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Risk Factors affecting the reproductive outcome of beef breeding herds in North Australia

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Abstract

Approximately half of Australia's beef breeding herds are located in northern Australia with reproductive performance being identified as having a significant impact on the profitability of these businesses. Although many of the risk factors affecting the reproductive performance of beef cattle have been previously identified, the relative contribution of major risk factors to key measures of performance, after partitioning the effects of other confounding variables, is lacking, particularly for extensive tropical rangeland systems typical of northern Australia.

The overall objective of the research described in this thesis was to, i) describe the reproductive performance of commercial beef breeding cattle in northern Australia and, ii) determine, and quantify the effect of the major risk factors associated with three key measures of reproductive performance (lactating cows becoming pregnant within 4 months of calving, cows failing to become pregnant within an approximate 12 month reproductive cycle, and foetal/calf loss between confirmed pregnancy and weaning). It was hypothesised that the major risk factors determining the probability of lactating cows becoming pregnant within four months of calving are similar to those determining the probability of foetal/calf loss between confirmed pregnancy and weaning. To address these objectives, a prospective population-based epidemiological study was conducted between 2007 and 2011 involving 78 commercial beef properties located across northern Australia.

Attainable and typical levels of reproductive performance for cow-age cohorts were described using a dataset containing 114,154 annual production cycles of performance data that represented approximately 78,000 heifers and cows managed in 142 breeding groups. Properties were assigned to one of four broad country types following a subjective assessment of the production potential of the grazing land and cross-referencing with pasture and vegetation descriptions reported by the herd owners/managers.

The typical overall reproductive performance of cows in the Northern Forest (57 live calves at muster per 100 surviving mature cows), was considerably lower than that for the other country types (71-83 live calves at muster per 100 surviving mature cows). This was due to typically much lower percentage of cows becoming pregnant within 4 months of calving, higher foetal and calf loss and higher estimated mortality of pregnant cows in the Northern Forest compared to the other genotypes. These findings are consistent with the generally poorer quantity and quality of pasture,

harsher environment and higher disease risk of cattle managed in the Northern Forest compared to the other country types.

Country type and predicted calving period were top-order determinants of pregnancy within 4 months of calving while lactating. The effect of cow-age class cohort was dependent on country type with the expected occurrence of lactating cows pregnant within 4 months of calving estimated to be 23.1-53.8, 38.1-61.6, 35.4-56.5 and 38.5-59.4 percentage points lower for first-lactation, second-lactation, mature and aged cows, respectively in the Northern Forest, compared to that in other country types. The expected occurrence of cows predicted to calve in July-September which became pregnant within 4 months of calving while lactating was 49 percentage points lower than those predicted to calve in December-January (15% v's 64%, respectively).

The outcome of the previous production cycle (including the current period of calving) and the average digestibility of dry season pasture in the current production cycle were ranked as the most important risk factors for non-pregnancy. Cows which grazed pasture during the dry season with an average dry matter digestibility of <55% were estimated to have 10.2 percentage points higher occurrence of non-pregnancy than those which grazed pasture with a dry matter digestibility of ≥55%. Cows predicted to calve between October and November were expected to have 15.6% fewer occurrences of non-pregnancy, compared to cows expected to calve between February and March.

Hip height of cows, risk of phosphorus deficiency and heat stress were determined as high-ranking contributors of foetal/calf loss in the study population. Foetal/calf loss was estimated to be 3.7 percentage points higher in tall cows than short cows. The association between temperature-humidity index (THI) and foetal/calf loss was dependent on country type, with the largest effect expected in the Northern Downs with 6.7 higher expected occurrence of foetal/calf loss estimated when the THI exceed 79 for at least two weeks during the expected month of calving. The associated effect of the risk of phosphorus deficiency was moderated by body condition score measured at the pregnancy diagnosis muster and country type. An 8 percent point higher expected occurrence of foetal/calf loss was estimated where risk of phosphorus deficiency was categorised as high in heifers and cows in poor body condition (BCS <2.5).

While there was evidence at a management group-level that infectious diseases had a significant impact on reproductive performance, the dominating effect of more universal risk factors such as nutritional, management and environmental factors were highlighted in this study. In groups which had evidence of widespread infection with bovine viral diarrhoea virus (BVDV) at the time of the pregnancy diagnosis muster (>80% seropositive with evidence of recent infection) there were 23 percentage points fewer expected occurrences of lactating cows pregnant within 4 months of calving, compared to that in groups with a low BVDV seroprevalence (<20%). In groups where there was widespread evidence of *Campylobacter fetus venerealis* (Cfv) infection at the time of the pregnancy diagnosis muster (≥30% of vaginal mucus ELISA test results positive), the percentage foetal/calf loss was 7 percentage points higher than where estimated prevalence of infection was lower (<30%).

The research presented in this thesis describes the first ever population based study of the performance of commercial beef cattle breeding herds in northern Australia and the factors affecting performance. Generally the major risk factors identified were different for each measure of reproductive performance, but overall all were non-infectious factors, primarily nutritional and herd management, and environmental factors. However, when outbreaks of infection with BVDV or Cfv did occur in breeding groups this did result in significantly lower reproductive performance. The findings from this research clearly identify what factors beef cattle producers and their advisors need to focus on when investigating poorer than expected reproductive performance, and provide the basis for future research to investigate the impact of specific management interventions to control these factors.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my research higher degree candidature and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

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I acknowledge that copyright of all material contained in my thesis resides with the copyright holder(s) of that material. Where appropriate I have obtained copyright permission from the copyright holder to reproduce material in this thesis.

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Publications included in this thesis

“No publications included”.

The writing of the chapters 4-9 included in this thesis has been completed in preparation for future publication. However, currently these are not under review.

Contributions by others to the thesis

This research thesis was completed in association with North Australian beef fertility project (CashCow), which was financially substantially supported by Meat and Livestock Australia. Professor Michael McGowan led the conception and design of the Cash Cow project in conjunction with Dr. Geoffry Fordyce, Mr David Smith, Professor Nigel Perkins, Dr Sandi Jephcott, Dr. John Morton and myself.

As the project leader, Professor Michael McGowan led the execution of the project. My responsibility as a PhD candidate and project manager included: the establishment of data housing systems, the integration of data and their management, responsibility for capturing the data within and the regional coordination of the Northern Territory and Kimberley region within Western Australia. The preparation of all data for analysis including data cleaning and verification was led and executed by myself with oversight by Professor Peter O'Rourke.

Several Cash Cow project team members shared responsibilities associated with the coordination of on-property data collection. These included: Mr David Smith - rangeland management and environment data, Mrs Dianne Joyner - faecal samples for NIRS testing, Dr Nancy Phillips - faecal and infectious disease sample receival and laboratory submission, Mr Tom Newsome and Mr Don Menzies - co-ordination and collection of cow data within Queensland.

Descriptive statistical analyses of data were all performed by myself with statistical oversight from Professor Peter O'Rourke (Chapters 4-6). Professor Nigel Perkins provided statistical oversight for analyses determining the factors associated with measures of reproductive performance. Preliminary univariate analyses and multilevel modelling were executed by myself. The execution of final multilevel modelling was performed by myself (Chapter 7), Professor Nigel Perkins (Chapter 8) and Dr. Tamsin Barnes (Chapter 9). Substantial intellectual contribution to the interpretation of the results obtained from these analyses was made by Professor Michael McGowan, Dr. Geoffry Fordyce, Professor Peter O'Rourke Mr. David Smith and Professor Nigel Perkins and industry stakeholder representatives.

The writing of the chapters included in this thesis has been completed in preparation for future publication and was primarily my responsibility as a PhD candidate. The writing of Chapters 1-8 & 10 was my sole responsibility as a PhD candidate with some editorial and writing contributions by Professor Michael McGowan, Professor Peter O'Rourke and Dr. Geoffry Fordyce. The writing of

Chapter 9 occurred in preparation for submission of a manuscript which was drafted by myself. The finalisation of this ‘in preparation’ manuscript was completed by Dr Geoffry Fordyce. Review of the final thesis was performed by Professor Michael McGowan, Professor Peter O’Rourke and Dr. Geoffry Fordyce.

Statement of parts of the thesis submitted to qualify for the award of another degree

The publications forming this thesis, and the data contained within, have not been submitted, in part or in whole, for a degree at this university or any other.

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Cattle, Reproduction, Herd Fertility, Breeding management, Pregnancy, Foetal loss, Calf loss, Abortion, Body condition score, Bovine viral diarrhea virus

Australian and New Zealand Standard Research Classifications (ANZSRC)

070206 Animal Reproduction 50%,

070704 Veterinary Epidemiology 40%,

070105 Agricultural Systems Analysis and Modelling 10%

Fields of Research (FoR) Classification

0702 Animal Production 50%

0707 Veterinary Sciences 40%

0701 Agriculture, Land and Farm Management 10%

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Glossary of abbreviations and reproductive indices

Adult equivalent	Measure of pasture intake. Usually defined as the amount eaten by a 454 kg (1,000 pound) steer at maintenance.
Aged cow	Cow with diminishing ability to forage or diminishing fertility. Start usually ranges from 8 years of age where environments cause early wearing, fracture and loss of teeth, to 13 years of age when stores of ova become depleted in some cows.
Annual conception rate	Percentage of cows in a management group (mob) that conceive within a one-year period. For continuously mated herds, this included cows that conceive between September 1 of the one year and August 31 of the next year.
Average	Total divided by the number of observations. This may be similar or very different to the median.
BBSE	Bull breeding soundness evaluation. This is a process that assesses five elements against standards that relate to calf-getting ability during natural mating.
Body condition score	Subjective assessment of the body tissue (fat and muscle) reserves of an animal. Five-point scale (1=poor 2=backward 3=moderate 4=forward/good 5=fat).
Bos indicus	Sub-species of cattle originating in tropical southern Asia. Brahmans are derived predominately from *Bos indicus* cattle.
Bos taurus	Sub-species of cattle originating in Europe, and includes British and continental breeds.

Branding rate	An ambiguous term that is most accurately defined as calves branded as a percentage of cows mated the previous year. It is very similar to weaning rate, but does not include calf mortality between branding and weaning.
Breedcow	Computer program for conducting economic analyses using herd structure, animal performance, and variable costs.
Breeder	Synonym for cow in a breeding herd.
Bull	Entire male cattle.
Bullock	Steer after it reaches mature height and weight.
Calf/foetal loss	See Reproductive wastage.
Central Forest	The Brigalow forested areas of central Queensland.
Calf output	Number of calves produced.
Cattle year	Twelve month period ending at a natural point in livestock transactions and handling, usually after the last weaning muster.
Closing numbers	Number of cattle at the end of the cattle year.
Conception rate	Number of animals known to have conceived over a defined period, divided by the number of non-pregnant animals mated.
Controlled mating	Non-continuous mating. The longest controlled mating is 7 months. Five months may allow mating after first weaning. Three months enables most calving to be complete before the next mating. Six weeks enables a maximum pregnancy percentage of 90% in healthy cycling beef heifers and cows.

Cow	Female cattle from the time the majority of a cohort calves for the first time.
Dry cow	Non-lactating cow, i.e. cow not suckling a calf.
Fertility	Having attributes that enable reproduction.
First-lactation cow	Cow during the period when the majority of her cohort is experiencing their first lactation.
Foetal ageing	Diagnosing age of a foetus using rectal palpation with or without the aid of ultrasound.
Head (of)	Colloquial term for cattle or other livestock. Almost always can be replaced by a specific term or excluded without loss of meaning.
Heifer	Female cattle up to the time the majority of their cohort has their first calf, after which the cohort is classed as first-lactation cows.
Heritability	Proportion of a trait that is transferred from one generation to the next; alternatively, the proportion of a trait that is due to variation in DNA.
Intercalving interval	The interval between two consecutive calvings.
Interquartile	The range between the 25^{th} and 75^{th} percentiles.
Lactation rate	Cows weaning a calf as a percentage of closing numbers (number of cattle at the end of the cattle year) within a group.

Live-weight production	Annual net live weight production per (retained) cow = Average live weight of cows at the end of the measured period x (1 – mortality rate) + Average weight of weaners produced x Lactation rate - Average cow live weight at the start of the measurement period.
Live-weight production ratio	Annual net live weight production / Average live weight of cattle in the paddock over a cattle year. (The latter represents feed intake and = Average cow live weight over the year + Average weight due to weaners over the year.) For example, a live weight production ratio of 0.45 equates to 45 kg net increase in live weight for every 100 kg of cattle grazing that paddock on average over a one year period.)
Maiden heifer	Heifer prior to first mating.
Mating outcome	Events and result for an individual cow over a reproductive cycle from the commencement of mating through to weaning.
Mating percentage	Number of bulls divided by the number of heifers and or cows in a mating group expressed as a percentage.
Mature cow	Cow after the time when her cohort has weaned their second age group of calves.
Mean	Synonym for average.
Median	Point where half the population is higher and half is lower = 50^{th} percentile.

Missing	Animals that fail to return for routine measures, but not including irregular absentees. It comprises mortalities, animals whose individual identity is lost, and those that permanently relocate either of their own accord or without being recorded by a manager.

Missing — Animals that fail to return for routine measures, but not including irregular absentees. It comprises mortalities, animals whose individual identity is lost, and those that permanently relocate either of their own accord or without being recorded by a manager.

Mortality rate	Cattle that have died as a percentage of the number known to be alive at a previous time.
Mustering efficiency	One minus the estimated proportion of absentee animals from a muster.
Neonatal	New-born, generally within a week of birth.
Northern Australia	Queensland, the Northern Territory, Pilbara, and Kimberley regions of Western Australia.
Northern Downs	Downs (naturally non-forested with black soil) areas of western Queensland, the Barkly Tableland, and Kimberley.
Northern Forest	Non-downs areas, north of a line from approximately Bowen to Karratha.
Opening numbers	Same as closing numbers from the previous year.
Operating margin	The return per kilogram of liveweight sold minus the cost of producing a kilogram of liveweight, expressed as $/kg.
PD round	The muster of a herd of breeding cattle for pregnancy diagnosis.

Percentage foetal/calf loss	The percentage of cows diagnosed pregnant that either fail to wean a calf or were not found to be lactating after expected month of calving.
Percentage points	When comparing the difference(s) between percentages for each measure of performance the absolute difference will be expressed in terms of percentage points increase or decrease. For example, the median percentage foetal/calf loss was 8 percentage points higher in cows in the Northern Forest (13%) compared to cows in the Southern Forest (5%).
Percentile	Demarcation point for a specified percentage of a population; e.g., 75th percentile is the point below which there is 75% of the population.
Perinatal	Within 48 hours of birth.
Pregnancy diagnosis	Diagnosing whether a heifer or cow is not pregnant (empty) or pregnant.
Pregnancy percentage	Heifers or cows pregnant at a specific time as a percentage of those mated.
Pregnant within four months of calving (P4M)	Lactating cows that become pregnant within four months of calving.
Property-year	A collective term referring to females within a property that were recorded during a common annual production cycle. A synonym for herd-year.
Quartile	A range within which 25% of animals occur.
Reproduction	Replication of an independent living being. In cattle, the most commonly used end point is weaning.

Reproductive wastage	Proportion of animals within a stage of the reproductive cycle that do not advance to a nominated subsequent stage. Most-commonly used for the percent of pregnant cows that fail to wean a calf.
RFID	Radio frequency identification device. A sealed transponder that emits a unique number when energised by an external device such as that in a wand or panel reader.
Second-lactation cow	A cow between confirmed pregnancy and weaning in the year after the majority of her cohort weaned their first calf.
Semen quality	Attributes of semen, primarily percent (forwardly-progressive) motile and percent morphologically normal, that indicate fertilising capacity.
Southern Forest	Non-downs areas outside the Brigalow country of central and southern Queensland.
Weaner	Calf permanently prevented from suckling its dam at the end of the reproductive cycle.
Weaner production	Lactation rate (weaners/retained cows) multiplied by average weaner weight.
Weaning rate	Cows weaning a calf as a percentage of those mated the previous year. Usually difficult to calculate as herd restructures and culling during pregnancy often prevents accurate information being available. Can be derived from multiplying annual conception rate by (1-foetal and calf loss rate).
Wet cow	Lactating cow or cow suckling a calf.

Wet-dry round	A breeding herd muster when lactation status of cows, but not foetal age, is determined. Usually the first muster of the year for branding and or weaning.
Year group	Cohort of cattle. In tropical Australia where calving peaks at the end of the year, the year group is the year in the second half of the financial year as it coincides with most branding; eg, calves born in 2012-13 are called the 2013 year group.

Chapter 1　Introduction

Beef cattle production is the primary form of land use in northern Australia with breeding as the major production activity. The north Australian beef herd represents 60% of the national beef herd and 9000 beef producing properties (Martin *et al.* 2013). A situation analysis of the north Australian beef industry has recently reported the industry as being in an unprofitable and unsustainable state (McCosker *et al.* 2010b) with the ratio of prices received to cost of production decreasing over time. Therefore, north Australian beef producers must continually increase productivity and/or reduce cost of production to remain viable. Furthermore, a key recommendation from this industry report was for funding bodies and herd managers to place increased emphasis on improving the reproductive performance of breeding herds to regain financial stability in commercial beef breeding businesses.

To ensure long term viability of the northern beef breeding industry, it is vital that herd managers have knowledge of what is an economically achievable commercial level of reproductive performance given their available resources and environmental conditions and a framework to allow a comparative assessment of current performance to diagnose lower than expected levels of reproductive performance. Additionally, without a systematic framework to monitor and compare actual levels of reproductive performance key management decision makers of herds are less likely to uptake reproductive advice and extension programmes, and therefore positive behavioural changes are less likely (Brownlie *et al.* 2011).

Increasing reproductive efficiency improves the business performance of properties as reduced cost of production arises from the expenses associated with the breeding herd being distributed across a greater number of progeny. With respect to commercial beef herds within the United States of America, it has been previously suggested that the relative economic value of improving reproductive performance is five times that of improving growth traits or the milk production of cows (Trenkle and Willham 1977). However, maximising reproduction does not necessarily maximise profitability. Improved economic status of properties can only be realised if the expense of altering management to improve the reproductive performance of herds is less than the economic return from altering management. When desired levels of performance surpass those routinely achievable on the available resources and conditions, the economic framework is typically not feasible as the cost of generating the required management change is usually greater than the financial return. Achievable commercial levels of performance for major beef producing areas of northern Australia are currently not known and therefore, diagnosing un-favourable commercial levels of performance is largely speculative and not determinable.

Some attempts have been made to define benchmark levels of reproductive performance in the literature using perceived estimates made by herd managers captured by surveys (Bortolussi *et al.* 2005a) or measured performances on research facilities or commercial properties involved in specific research projects (Burns *et al.* 2010). These estimates have been useful in guiding investment into areas of research and providing some basis to compare performance across time. However, their representativeness of actual performance in commercial industry within some parts of northern Australia is problematic. The benchmarks based on reproductive performance measured on research facilities are potentially not representative of commercial beef breeding properties and are likely to overestimate typical levels of performance due to reduced herd sizes, heightened management intensity and operating at above best practice standards. Alternatively, levels of reproductive performance determined by survey are also likely to be over-estimates given there is often discrepancy between perceived performance levels and those occurring in reality as demonstrated by Schatz and Hearnden (2008) who measured a much lower reproductive rate to that reported by herd managers in an extensive face to face survey. This misrepresentation of actual levels of performance by herd managers is likely to have arisen due to the lack of basic business records and the lack of standardisation between and within industry stakeholders for calculating measures of reproductive performance in extensively managed breeding herds, particularly how herd management decisions that occur between mating and pregnancy diagnosis such as culling (removing), spaying (sterilizing), and re-mating are incorporated in the calculation of the measure of reproductive performance.

Equal in importance to determining commercially achievable levels of reproductive performance is an understanding the major sources of variation in reproductive performance in commercial beef breeding cattle. Large variability exists in the reproductive performance of north Australian beef herds (Bortolussi *et al.* 2005a) due to a large number of known factors that affect the capacity of beef cattle to either conceive, maintain a pregnancy and wean a calf (Hasker 2000) and have been recently comprehensively reviewed (Burns *et al.* 2010). Historically, many studies have evaluated the impact of known risk factors while attempting to minimise the impact of other risk factors or have evaluated factors at a single level (Hasker 2000). For example, a study involving 14 commercial cattle properties located throughout the Northern Territory identified a strong association between the animal-year level factor liveweight between calving and weaning and pregnancy percentage in first-lactation cows (Schatz and Hearnden 2008). Additionally, there have been some detailed studies that have quantified the impact of known risk factors using longitudinal datasets derived from research station databases (O'Rourke *et al.* 1995a; O'Rourke *et al.* 1995b). However, there was no quantification of the overall variability associated with factors operating at different levels or the relative contribution of known risk factors and probability of cows becoming pregnant, or risk of cows or heifers failing to contribute a live calf at muster under commercial conditions. Explaining the major sources of variation in reproductive performance of commercial beef breeding cattle of northern Australia is necessary for development of appropriate management intervention and informing producers what management practices they need to focus on to maximise the percentage of breeding females becoming pregnant or minimising their risk of failing to contribute a live calf at muster. In addition, such information is also needed to prioritise future research, development and extension directions and investment. In circumstances such as when most variation in reproductive performance is explained by known risk factors, future investments should be prioritised towards the adoption of known information and reasoning. Alternatively, if little variation is explained by known factors, future research investments should aim to identify the major sources of the unexplained variation in performance.

Study designs based on the collection of large volumes of individual animal data on commercial enterprises has recently become logistically feasible due to the moderate adoption of individually identifying heifers and cows using National Livestock Identification System (www.nlis.com.au) compliant devices and the development of computer packages that allow the crush-side capture of individual cattle data at commercial processing rates. The major focus of this research thesis was to employ epidemiologic-research methods to increase the understanding of the prevalence of risk factors that affect the reproductive efficiency and productivity of a population of commercial beef breeding herds, and to use explanatory multilevel models to identify the major determinants and their impact on the probability of cows either becoming pregnant while lactating, failing to become pregnant or pregnant heifers and cows failing to contribute a live calf at muster (Dohoo *et al.* 2001; Mason 2001). It is hypothesised that the major risk factors determining the probability of lactating cows becoming pregnant within four months of calving are similar to those determining the probability of foetal/calf loss between confirmed pregnancy and weaning. A second major focus of this research thesis is to describe the reproductive performance of a selected population of commercial beef herds across northern Australia and compare to those not included in the study.

Chapter 2 Review of the Literature

This review describes the north Australian beef industry and the relevant herd management practices and policies of owners/managers of beef breeding businesses. The current methods of monitoring reproductive performance and the level of productivity of beef herds within this region are summarised, and the current understanding of the factors affecting performance of extensively managed rangeland beef breeding cattle is reviewed. The relevant literature was identified using electronic data bases for printed publications printed in English. In some instances, publications not meeting these criteria were also cited. Preference was given to those publications more recently published and for peer-reviewed publications.

2.1 Introduction: Beef industry in northern Australia

The North Australian beef industry encompasses beef production within northern Western Australia, the Northern Territory and Queensland, and represents approximately 60% of the national beef herd and 9000 beef producing properties (Figure 2-1) (Martin *et al.* 2013). The northern beef industry is an important contributor to the Australian economy, estimated to contribute approximately five billion dollars annually, with a heavy reliance on the live export trade (Gleeson *et al.* 2012). For those properties that are heavily reliant on the live export trade (Figure 2-2), breeding females generally represent a greater proportion of the herd to ensure large numbers of young, store conditioned cattle are able to be turned off each year (Gleeson *et al.* 2012). Consequently, profitability is increasingly dependent on reproductive performance and female mortality, and is susceptible to heightened risk from seasonal conditions and market influences (Sullivan 1992). The profitability of northern beef cattle enterprises has recently been reported as declining in terms of trade over time (McLean *et al.* 2013) due to the lack of productivity gains, diminishing returns from reduced turnoff, lower beef prices and increased property debt (Gleeson *et al.* 2012). It has been widely documented that the reproductive performance of cattle in northern Australia is lower than that of temperate southern Australia (Entwistle 1983). Low reproductive performance in northern Australia is a result of multiple factors including pastures of poor quality and quantity during the dry season, extreme temperatures and humidity during dominant calving and mating periods, and large variability in seasonal rainfall (Entwistle 1983).

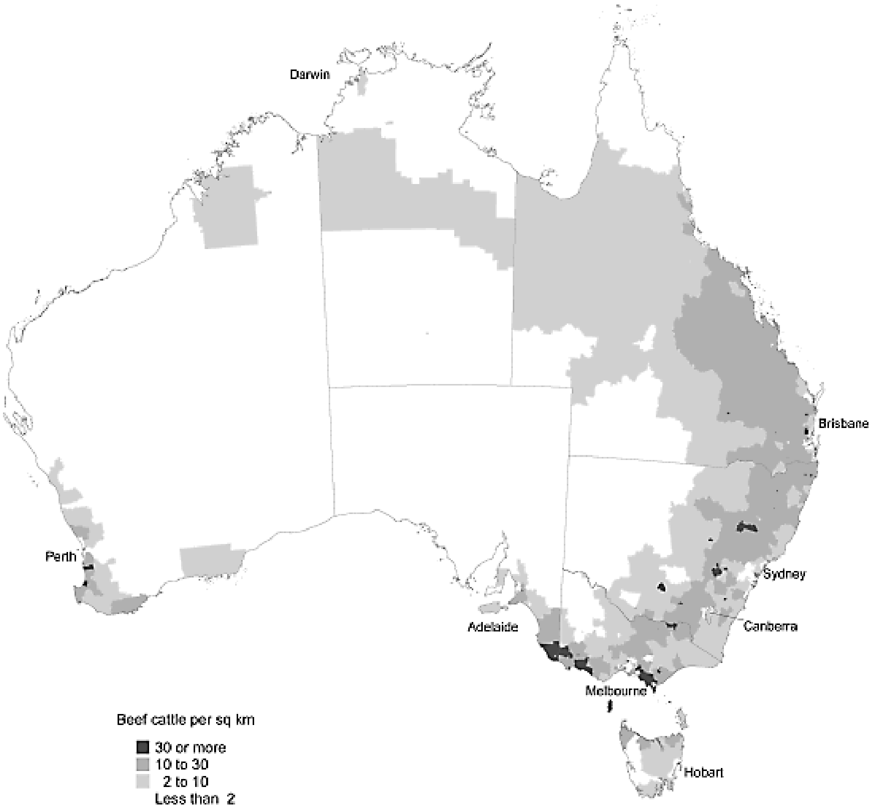

Figure 2-1: Distribution of beef cattle within Australia (ABS 2005).

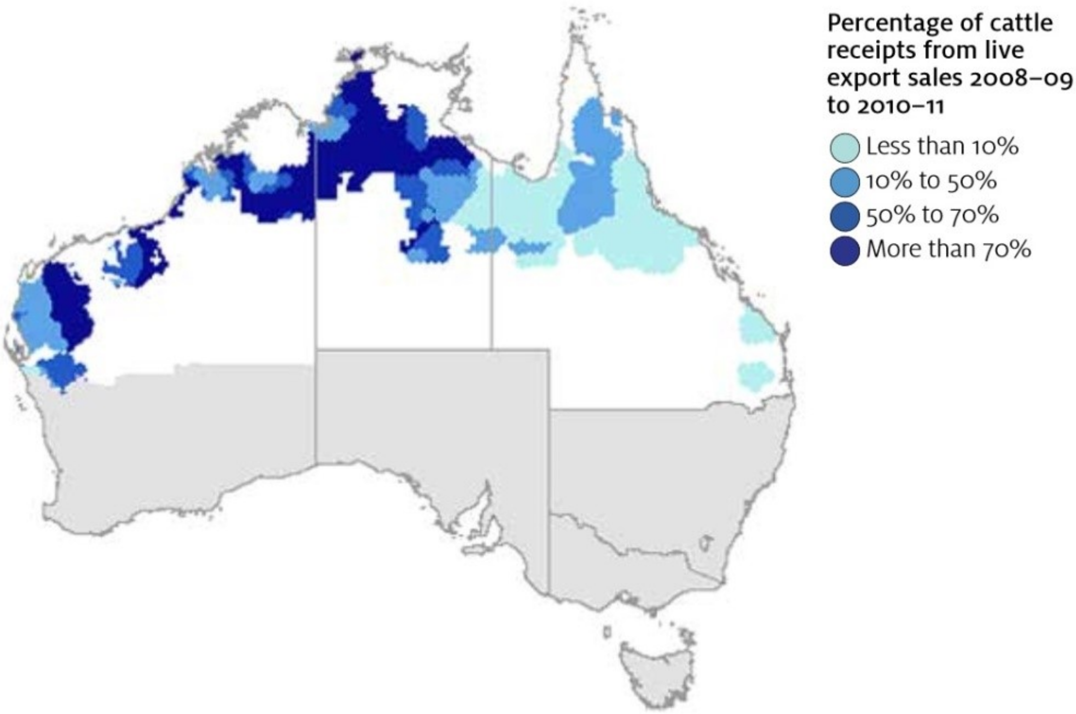

Figure 2-2: Map of North Australian live export region (Gleeson *et al.* 2012).

Property sizes vary greatly within northern Australia. An average property size of 44,000 ha was reported following an extensive survey of north Australian producers (O'Rourke *et al.* 1992). However, property sizes tend to be smaller in the more intensively developed higher rainfall areas of Southern Queensland while tending to be very large, averaging up to 370,000 ha in the extensively managed parts of northern Northern Territory and Western Australia (O'Rourke *et al.* 1992; Cowley *et al.* 2014). A significant percentage of beef producing properties within northern Australia are corporately owned and are often managed as integrated systems (Bortolussi *et al.* 2005b). Such systems, typically position the breeding enterprises within the northern and western Queensland and the Barkley Tableland and transfer weaned progeny to affiliated properties in the southern and central Queensland for finishing (Whan *et al.* 2006; Gleeson *et al.* 2012). Indigenous communities and the Indigenous Land Corporation also own a significant portion of northern Australia that is suitable for beef production (Gleeson *et al.* 2012).

Cattle numbers vary across time and are dependent on seasonal conditions and level of development. A survey of 375 north Australian beef producers conducted during 1996 and 1997 highlights vast differences between regions across northern Australia for size of breeding herds (Bortolussi *et al.* 2005b). Approximately half of properties reported cow herd sizes greater than three thousand cattle, with herd sizes exceeding twenty thousand being observed in the northern parts of Queensland, Northern Territory and Western Australia. In contrast, median cow herd sizes of <1000 were recorded for southern and central parts of Queensland. A greater proportion of inland properties in southern and central Queensland had cow herd sizes >1000 than coastal properties. A greater difference between southern and northern parts may potentially exist as since these industry surveys were conducted greater increases in cattle numbers have been reported for northern parts of northern Australia. A comparison between the 2001 and 2011 Australian Bureau of Statistics Agricultural Census data appears to suggest that the beef cattle population across most parts of northern Australia is increasing over time, with greatest increases in cattle numbers being observed in central western Queensland and the Kimberley region.

The live export trade is an important market for the north Australian beef industry (Bortolussi *et al.* 2005b). The live export region within northern Australia (Figure 2-2) largely represents the northern parts of the Northern Territory and Western Australia, and north-west Queensland (Martin *et al.* 2013), and supplies approximately 75-80% of the market (Riley *et al.* 2002). Producers with the greatest reliance on the live export trade are within the north-western parts of the live export region, of which more than 70% of their annual sales are directed towards this market. In contrast, central and southern Queensland focus primarily on supplying beef for frozen or chilled export and domestic beef markets (Gleeson *et al.* 2012). Therefore, these regions have a greater tendency to operate both breeding and fattening enterprises.

2.2 Climatic and environmental conditions of areas used for beef cattle production within northern Australia

The northern rangelands vary greatly in terms of pasture production, fertility and soil types and therefore their ability to support animal production (Tothill and Gillies 1992). The north Australian rangelands are located within the arid subtropics and tropics; are largely based on unimproved native or naturalised pasture species (Coates *et al.* 1997) and are based on soils with varying degrees of phosphorus deficiency. Additionally, due to the variability in soil types, fertility, and rainfall the ability to establish and maintain improved pastures is variable.

Summer temperatures are high throughout northern Australia, ranging between 25-40^{o}C with heatwaves commonly experienced with maximum temperatures up to 50^{o}C. Lower temperatures are experienced in a southerly direction during winter, with greatest diurnal variation in the south. On average, daily minima and maxima exceed 9^{o}C and 25^{o}C during winter above the tropic of Capricorn with lower temperatures being experienced in the south eastern regions of northern Australia. Frosts are frequent below the tropic of Capricorn during winter.

The timing, amount and intensity of rain, and follow-up rains are major factors affecting the ability of rangelands to support cattle production (Figure 2-3). Rainfall in the tropical parts of northern Australia is highly seasonal, with 90% of the annual rainfall falling between November and April during the ‘wet’ or ‘monsoon season’ (Nicholls *et al.* 1982). This varies across northern Australia with winter rains increasing in a southerly direction and along the eastern coast (Nicholls 1984). The timing of the transition to wet conditions or ‘onset’ and the occurrence of monsoons are highly variable (Lo *et al.* 2007; Pope *et al.* 2009) and associated with high relative humidity. Equally variable is the timing of the cessation of the wet season, however typically the dry season commences in May. Up to 30% of the annual rainfall occurs prior to onset of the monsoon in the form of storms. However, the monsoon season is associated with heavy, widespread rains that contribute significantly to the annual rainfall (Nicholls 1984; Pope *et al.* 2009).

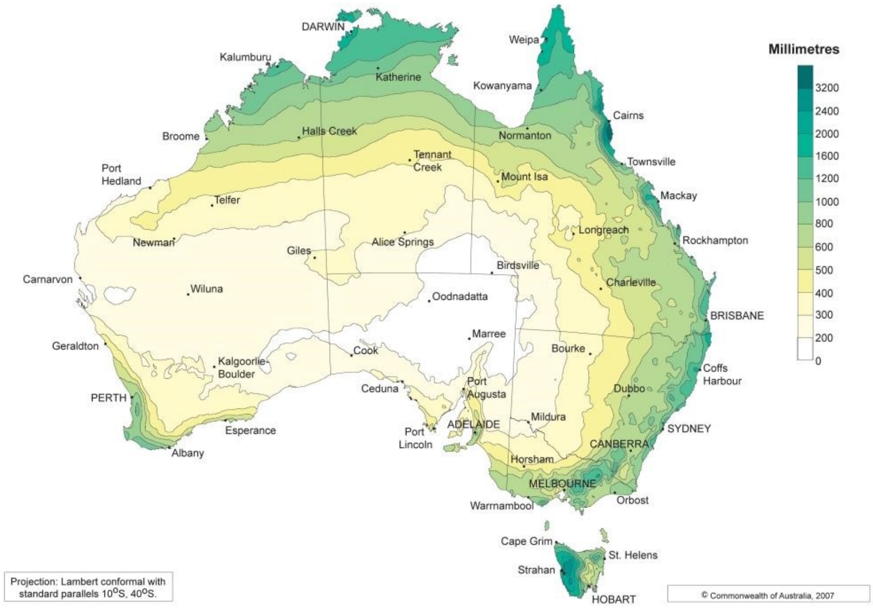

Figure 2-3: Annual average rainfall across Australia based on data collected during 1976-2005. *Source*: Australian Bureau of Meteorology.

Bioregions (Figure 2-4) are large, geographically distinct areas of land that contain similar biophysical characteristics such as climate, ecological features and plant and animal communities (Williamson *et al.* 2011). Bioregions of significance to cattle production in Northern Australia include the Mitchell Grass Downs, Victoria River District (Victoria Bonaparte and Ord Victoria Plain), Brigalow Belt and Mulga Lands.

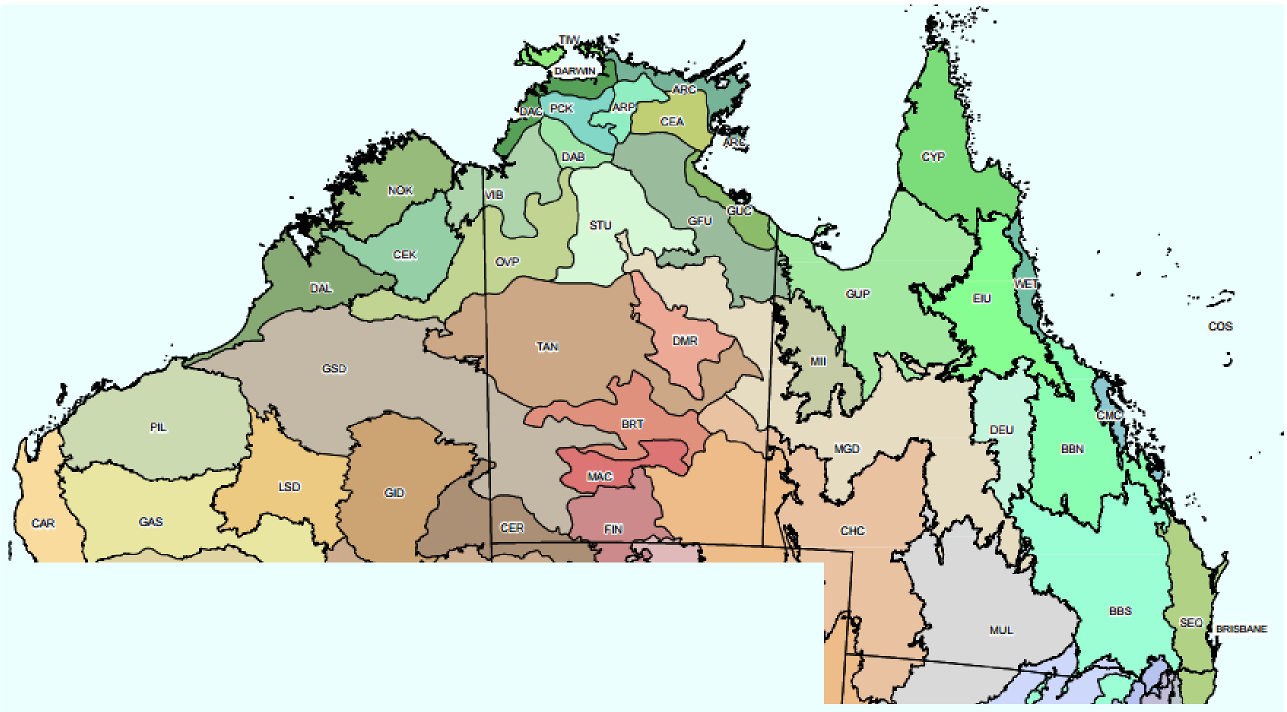

Figure 2-4: Map depicting biographic regionalisation of northern Australia. ***Adapted from: www.environment.gov.au*** **(Abbreviations: Mitchell Grass Downs, MGD; Victoria Bonaparte, VIB; Ord Victoria Plain, OVP; Brigalow Belt, BBN and BBS; and Mulga Lands, MUL).**

Within the Northern Territory, areas of significant grazing value include the Mitchell Grass Downs of the Barkly Tableland and the Victoria River District. The Mitchell Grass Downs extends across central-eastern Northern Territory into central Queensland and is highly utilised. The climate is hot and semiarid with summer dominant rainfall. It consists of expansive treeless plains on cracking clay soils with the major pasture resource being Mitchel grass (*Astrebla* spp.). The Victoria River District is located in the northern-west of the Northern Territory extending into Western Australia and consists of alluvial plains and plateaus and a number of river basins. The climate is monsoonal with an annual rainfall of approximately 500mm (Bastin 2008). The predominant pasture communities within the Victoria River District include perennial tallgrass pastures (e.g. *Chrysopogon, Sorghum*, and *Heteropogon* spp.) and less productive midgrass hummock grassland pastures (e.g. *Triodia* spp.) (Tothill and Gillies 1992).

The Mitchell Grass Downs, Mulga Lands and the Brigalow Belt comprise the bulk of Queensland's rangelands. The Brigalow Belt is located in the central eastern and southern regions of Queensland and includes various land types such as rugged ranges, undulating hills and alluvial plains, with vegetation including eucalypt woodlands and open brigalow (*Acacia harpophylla*) and gidgee forests (*Acacia cambagei*). The clay and loamy soils are highly fertile however, the native pastures are sparse and unproductive (Tothill and Gillies 1992). Large portions of these regions have been cleared and over sown with improved pastures (e.g. *Cenchrus* spp.) and legumes (Bortolussi *et al.* 2005d) to improve the nutritional quality and increase vegetation yields (Ash and McIvor 1998).

East of the southern Brigalow belt is referred to as the south east Queensland bioregion, which broadly represents the southern speargrass country. The soils are variable in fertility with forest bluegrass (*Bothriochloa bladhii*) commonly found along river and creek banks and on heavier black clay soils. In the poorer soils black speargrass (*Heterpogon contortus*) pastures are predominantly found. This region is characterised by open forests and woodlands vegetated by silver-leaved (*Eucalyptus melanoploia*) and narrow-leaved ironbark (*Eucalyptus crebra*) and spotted gums (*Eucalyptus maculata*) (Partridge 1993). However, much of the vegetation within this region has been cleared to encourage satisfactory grass growth and over sown with improved pastures (e.g. *Panicum* and *Chloris* spp.) and legumes, which have extensively improved their productivity.

The Mulga Lands are located in south-west Queensland and are characterised by undulating plains and low hills which are predominantly vegetated by mulga (*Acacia aneura*) and eucalypt woodlands. Generally, Mulga is associated with shallow red earths that do not readily support the establishment or maintenance of improved pastures (Pressland 1984) and are generally less productive than other parts of Queensland. Mulga is an important top-feed that is often used during dry seasons and in drought feeding.

Regions of cattle production considered to be less productive include areas within northern parts of the Northern Territory, the Gulf of Caprentarea and the Cape York Peninsula. These regions include areas subjected to seasonal waterlogging, are dominated by low quality tallgrass and spinifex hummock pastures and are vegetated by teatree and stringy bark woodlands (Tothill and Gillies 1992). Areas of alluvial grey cracking clays found in the Gulf regions are dominated by bluegrass-browntop pasture communities (e.g. *Dicanthium fecudum)* and are of medium pasture quality (Tothill and Gillies 1992). The Kimberley region of Western Australia is characterised by hilly to mountainous country, low extensive plains, ranges and gorges. Areas within the Kimberly used for cattle production include those associated with the Ord Victoria Plains to the east, which are of moderate quality and those to the west dominated by spinifex hummock pasture communities (e.g *Triodia*, *Plectrachne* spp.) on various soil types and are of marginal to low pastoral value.

2.3 Beef cattle management practices within northern Australia

A common aim of beef production systems that utilise rangelands worldwide is to balance the grazing resources with animal requirements while optimising production through employing timely and effective management decisions. Within Australia, differences exist between beef cattle production systems within the temperate zones of Australia to those in the semi-arid subtropics and tropics of northern Australia. These differences impact on the reproductive management and performance of herds for example, in southern parts soils are generally of higher fertility and winter rain and resulting winter forages support increased annual production and facilitate increased intensity of management. Similarly, southern parts of Queensland incur less environmental stressors than those within the tropical regions (see section 2.2). Additionally, the extensiveness of operations varies greatly within northern Australia with size of operations averaging 699,400 ha in the Barkly tableland region of Northern Territory to 2,500 ha in the high rainfall intensively managed regions of south eastern coastal Queensland (Gleeson *et al.* 2012). Regional surveying of herd managers has been completed on a number of occasions with management practices varying accordingly to accommodate extensiveness of operations and baseline available nutrition (O'Rourke *et al.* 1992; Bortolussi *et al.* 2005a; Bortolussi *et al.* 2005b; Cowley *et al.* 2014).

Summer rains are received earliest in south-eastern parts of Queensland, followed by tropical regions of Northern Territory, Queensland and Western Australia with more inland areas receiving summer rains later. Similarly, to synchronise lactation with the best nutritional period of the year, commencement of mating and resulting peak calving activity occurs earliest in southern Queensland (Bortolussi *et al.* 2005a). Within northern Australia, preferred commencement of calving typically ranges between August, in southern regions, to December, in northern parts.

Duration of mating is longest in the more extensively managed beef herds of northern Australia with continuous mating commonly practiced in these herds (Bortolussi *et al.* 2005a) due to perceived difficulties in controlling bulls (McCosker *et al.* 2010a). The resulting calving pattern is difficult to manage as calves are born throughout the year and those calves born late in the wet season are of insufficient weight to be weaned at musters conducted early in the year. Consequently, a proportion of cows lactate throughout unfavourable times of the year; a significant factor associated with the reduced body condition and reproductive performance in the subsequent year (Fordyce *et al.* 1990). Under year-round mating systems two annual musters are required to reduce liveweight loss and mortality and increased percentage of cows becoming pregnant during the wet season (Sullivan and O'Rourke 1997). Alternative production systems with continuous mating include the segregation of heifers and cows according to predicted periods of calving which allows refined management of groups of females of similar nutritional demands and calving times (Braithwaite and deWitte 1999a, 1999b). Also, segregation of cows according to expected periods of calving allows more effective use of supplementation and mustering.

Where controlled mating is practiced in the more extensive, northern parts of northern Australia the average length of mating is approximately 7 months with bulls introduced at various times between December and March (O'Rourke *et al.* 1992) to mitigate risk of cow mortalities arising from conceptions occurring in response to weaning and consequently cows calving late wet/early dry seasons and lactating throughout the entire dry season. In the southern, more endowed parts of northern Australia the majority of enterprises mate bulls for restricted periods ranging between 2-6 months. Although lower branding/weaning rates may result from restricted mated periods, in areas where market drivers and growth rates of young cattle determine older optimum turn-off ages, branding/weaning rates exceeding 75-80% have been reported to be associated with only marginal economic benefit (Burns 1990; Sullivan 1992).

The majority of beef producing herds across northern Australia are self-replacing (Bortolussi *et al.* 2005a). In southern regions, where it is not unrealistic for heifers to reach 300kg at the time of mating, they are commonly mated as yearlings. However, in extensive regions of northern Australia heifers are typically first exposed to bulls at approximately 2 years of age. Further, as a result of this delay in timing of first deliberate exposure to bulls it is not uncommon to find 10 to 20% of heifers are already pregnant at the commencement of planned mating due to difficulties in controlling bulls. Under extensive management systems the early lifetime performance of heifers and longevity within the herd was associated with the timing of their first pregnancy (McCosker *et al.* 2012).

Culling is generally practiced on all enterprises across northern Australia with the overall objective to remove sub-fertile females (cows which failed to lactate in the previous year and are in fat condition or failed to become pregnant after calving), and those females at risk of not surviving (generally aged cows and cows likely to calve during the dry season). Under harsh or drought conditions, the probability of survival for aged cows is less than that for cows of younger ages (Fordyce *et al.* 1990). A greater proportion of enterprises cull females for poor reproductive performance in southern parts of northern Australia relative to more extensive regions (Bortolussi *et al.* 2005a). In the more extensive regions of northern Australia, a lower proportion of properties conduct pregnancy diagnoses on the whole herd and rather, only perform pregnancy diagnoses on non-lactating cows to identify non-pregnant cattle fit for turn-off. Additionally, due to the difficulty in controlling bulls, and with many herds being continuously mated, surgical spaying is practised to prevent pregnancies and ensures future marketability of surplus-to-requirement females. In contrast, marketing of pregnant cattle is less difficult in southern parts of northern Australia and consequently, a greater proportion of enterprises adopt whole herd pregnancy diagnoses and culling for non-pregnancy or out-of-season calving (Bortolussi *et al.* 2005a).

In heifers and cows, weaning potentially preserves body condition or enables recovery of body condition and if appropriately timed can increase reproductive performance and reduce mortality risk (Fordyce *et al.* 1990). Calves are weaned at slightly older ages (+1 month) in the more endowed, southern parts of northern Australia. Live weight of calves at weaning is reported as 20-70 kg heaver in southern parts of northern Australia, compared to northern (Bortolussi *et al.* 2005a). In northern areas, two or more weaning events are typically conducted, during the periods April-June and August-November. In contrast, one weaning event is typically completed in areas practising controlled mating of less than 4 months duration.

2.4 Calculating indices of reproductive performance

2.4.1 Introduction

To evaluate the reproductive performance of a beef cattle herd requires collection and analysis of appropriate data. Consistent methods of assessment, accurate data recording and standardised approaches are required when summarising and interpreting reproductive data to measure reproductive performance. A multitude of methods, varying in ability to accurately summarise actual performance, have been used to describe the reproductive performance of extensively managed beef herds. Weaknesses in their derivation mostly relate to accounting for herd management decisions between mating and pregnancy diagnosis or weaning, such as the removal of cull females and addition of replacement females to herds. Differences in methods of accounting for these management decisions make comparisons between herds or properties difficult and their interpretation often misleading and confusing. The individual identification of cattle and use of computer packages that allow the capture of cattle data against individual animals is increasingly being adopted by commercial enterprises and overcomes a large number of limitations historically encountered when monitoring reproductive performance. The main measures of reproductive performance commonly used are described below.

2.4.2 Pregnancy diagnosis and estimated foetal age

Pregnancy diagnosis of a herd is essential to support informed management decisions, such as segregating of heifers and cows for specific nutritional management, timing of mustering events, and culling or rebreeding decisions. Pregnancy diagnoses and foetal aging can be used to derive either the estimated date of conception or parturition. Dates of conception and calving are typically predicted using the estimated foetal age at the date of pregnancy diagnosis and projected either forward or backward using an assumed gestation length.

Associated errors with estimated conception and calving dates arise due to the naturally occurring variation in gestation length and errors associated with predicted foetal ages (O'Rourke 1994). Additionally, when monitoring reproductive performance within commercial beef herds, 'conception date' usually relates to the estimated date of conception for the confirmed pregnancy as the routine identification of all conceptions is not possible due to the extended periods between musters and the high incidence of embryonic mortality. Embryonic mortalities, defined as mortalities occurring between fertilisation and day 45 of gestation (Committee on Bovine Reproductive Nomenclature 1972), have been documented to range between 17-38% in research studies conducted within northern Australia (Burns *et al.* 2010). Thus, heifers and cows diagnosed early pregnant soon after the conclusion of mating are at increased risk of being identified as failing to deliver a calf due to embryonic mortality than those cows in which pregnancy is diagnosed some months after end of mating.

Cows carrying male calves tend to have a slightly longer (1-3 days) gestation compared to cows carrying heifer calves (Casas *et al.* 2011) and body condition at the time of pregnancy diagnosis has also been associated with gestation length (Silveira *et al.* 2015). Gestation length is also a known inter- and intra-breed characteristic with average breed specific gestation lengths ranging between 279-293 days (Burris and Blunn 1952; Corbet *et al.* 1997; Thrift 1997). *Bos taurus* breeds tend to have gestation lengths about 10 days shorter than *Bos indicus* breeds, which on average have a mean gestation length of 293 days (Plasse *et al.* 1968). Composite breeds consisting of both *Bos indicus* and *Bos taurus* genotypes have gestation lengths intermediate between *Bos taurus* and *Bos indicus*.

Several methods are commonly used to diagnose pregnancy, and estimate foetal age. Currently, the most practical methods of conducting pregnancy diagnosis and foetal aging on large numbers of females are rectal palpation and transrectal ultrasonography. In intensive beef operations, the use of ultrasonography is increasing however, in extensive beef herds the use of rectal palpation is the most common and efficient method of conducting this procedure. Transrectal palpation is cheap, reliable and relatively accurate, depending on the experience and skill of the technician. A skilled and experienced technician using rectal palpation can diagnose pregnancy from as early as 30 days gestation until full term (Youngquist 2007). Diagnostic error is largely dependent on the technician, infrastructure and management of cattle prior to pregnancy diagnosis (AACV 2004). The sensitivity and specificity of pregnancy diagnosis via rectal palpation are relatively high. However, accuracy of foetal age estimates, and therefore conception and calving dates, are variable (O'Rourke *et al.* 1992). Estimation of foetal age via rectal palpation is most accurate during the first half of gestation (Youngquist 2007) and has a precision of approximately 2 weeks with estimated foetal ages tending to be under-estimated at early stages while over-estimates are more common in later pregnancies (O'Rourke 1994). Therefore, in practical application, conducting pregnancy diagnoses approximately 6 weeks following a 3-4 month mating period or two pregnancy diagnoses conducted 4 months apart (ie April/May and August/September) under continuous mating systems will provide the greatest precision in commercial situations.

Like the rectal palpation method, accuracy and efficiency of the use of real-time B-mode ultrasound scanning to detect pregnancy in cattle is dependent on the facilities, the treatment of cattle prior to diagnoses, operator expertise and experience and stage of pregnancy (AACV 2004). The use of ultrasound to examine the reproductive tracts of cattle has been comprehensively explained (Ginther 1995).

Real-time B-mode ultrasound scanning can detect pregnancy from 17 days however, is most accurate between 5 and 12 weeks with an estimation of foetal age expected to be within 2 weeks of actual (AACV 2004). Estimating the foetal age of pregnancies greater than 15-16 weeks, particularly in multiparous cows, using ultrasonography is time consuming due to the fact that foetal structures such as the orbit of the eye and hooves can be difficult to visualise sufficiently well to measure accurately. The use of ultrasonography to diagnose pregnancy offers increased accuracy during the early stages of pregnancy and the ability to determine sex of the foetus. However, associated issues with stages of gestation, efficiency and cost preclude their routine use in commercial beef herds.

A number of conflicting studies have investigated the effect of rectal palpation and rectal ultrasonography on embryonic and foetal death. Franco *et al.* (1987) estimated foetal deaths due to rectal palpation between days 42 and 46 of gestation between 9.5-11.8%. However in contrast, Paisley *et al.* (1978) and Alexander *et al.* (1995) who also investigated foetal losses due to rectal palpation were unable to conclude that rectal palpation induced an increased rate of embryo and foetal mortality. It is generally considered that if rectal palpation is a cause of embryonic and foetal loss, its incidence is low (Youngquist 2007). Alternative methods to diagnose pregnancy also exist such as, the profiling of progesterone levels. However, their practical application for commercial beef enterprises is limited.

2.4.3 Measures describing the prevalence of pregnancy in a group of heifers or cows

Measures describing the ability which heifers and cows achieve pregnancy differ slightly depending on mating management systems. In control mated herds it is the prevalence of pregnancy after a defined mating period. Whereas, in management groups that are mated for extended periods it is the prevalence of pregnancy as there is usually little knowledge when cows calved. The most commonly used measure to describe the overall success of pregnancy refers to the proportion of cows either mated or pregnancy tested that achieved pregnancy (Johnston *et al.* 2013), which is typically expressed as a percentage and commonly referred to as pregnancy rate. Pregnancy percentage is a particularly useful indicator of reproductive performance with short mating periods and is a measure of mating success. However, as an overall indicator of reproductive performance a major limitation of pregnancy percentage is that pre-, peri- and post-natal losses are not represented.

The term 'rate' is used liberally in relation to pregnancy and is often used when referring to proportions, which is incorrect. By definition, a true 'rate' represents the probability of an event in only those at risk animals during a known time period. As there is often no consideration for either a cow's or herd's opportunity to become pregnant such as, time since calving or length of mating period 'pregnancy percentage' or 'percent pregnant' is more appropriate. It is also for similar reasons that inter-herd comparisons for percentage pregnant must be carefully interpreted as differences in management or historical events such as, duration of mating, timing of the pregnancy diagnosis, lactation status, calving distribution has substantive effects on the usefulness of such comparisons.

Annual pregnancy percentage is most commonly presented as an overall summary of the mating success of a herd or management group. However, due to prolonged periods of post-partum anoestrus being associated with lactation and attributed to low probability of pregnancy within north Australian (Entwistle 1983), measures of pregnancy percentage are commonly sub-categorised by lactation status to describe the proportion of lactating and non-lactating cows which become pregnant (O'Rourke *et al.* 1995a; O'Rourke *et al.* 1995b; Sullivan and O'Rourke 1997). The percentage of lactating cows which become pregnant describes the proportion of lactating cows that potentially can contribute two calves in two successive years. Additionally, particularly within the northern downs regions of Northern Australia, management groups of breeding females are determined by their expected time of calving due to its association with cow survivability (Fordyce *et al.* 1990), weight of the calf at weaning and the probability of the cow becoming pregnant and contributing a calf in the subsequent year and therefore, the annual gross margin produced per cow (Braithwaite and deWitte 1999a). As such, measures of pregnancy for lactating cows are also sub-categorised by their previous expected time of calving.

2.4.4 Measures based on time from event data

Measures describing pregnancy based on time of event data such as time to pregnancy from calving or mating start date (Johnston and Bunter 1996; Johnston *et al.* 2013) and interval from calving to subsequent calving (inter-calving interval) have been used to describe reproductive performance. Prior to the moderate adoption by commercial herd managers to individually identify heifers and cows using National Livestock Identification System (www.nlis.com.au) compliant devices, it was logistically unreasonable to derive measures describing time to pregnancy since calving, while time to pregnancy since mating start date is less informative for herds with extended mating periods. Additionally, as many north Australian beef breeding herds do not routinely conduct whole herd pregnancy testing, such measures are used infrequently as the data required for their derivation is not often available.

The inter-calving interval has been used to measure reproductive performance in Australia and many other countries (MacGregor and Casey 1999). On an individual cow's reproductive lifetime basis, the inter-calving interval is considered to be a reasonable measure of reproductive efficiency. However, using data derived from a large South African beef herd, MacGregor and Casey (1999) concluded that when calving interval was used to evaluate animal-level reproductive performance, adjustment for previous calving date is required, due its confounding effect. As cows with the shortest inter-calving interval are typically those that calve later in the calving period and therefore, selection of cows based on shortest calving interval would preferentially select cows calving later during the calving season and result in the selection of cows that eventually fall out of the calving window. Consequently, the trait ' days to calving', defined as the interval between the mating start date and when the cow or heifer subsequently calves, has become the standard trait to evaluate the genetic merit of naturally mated females (Meyer *et al.* 1990).

Inter-calving interval is also used as an aggregate measure to describe the reproductive performance of a herd or group of females (Holroyd *et al.* 1977; Sawyer *et al.* 1991; Corbet *et al.* 2006).

However, the use of inter-calving interval to describe reproductive performance has been more widely reported in the dairy industry and is known to have significant limitations (Morton 2010).

A natural right skewness exists in the distribution of inter-calving interval data. This non-normal distribution of the inter-calving interval values typically results from data appearing truncated from the left due to the biological minimum limits of gestation and interval from calving to conception. However, the arithmetic mean is often used to describe the reproductive performance of a herd, which is potentially an inappropriate measure of central tendency for non-normally distributed data (Petrie and Watson 2013). Additionally, the mean can be greatly influenced by extreme or outlier values recorded in small sized herds (Morton 2010). In right skewed data, the geometric mean (back calculation of mean for log-transformed data) and median are a better measure of central tendency. However, these do not appear to be widely used in studies reporting reproductive performance in the beef industry (Holroyd *et al.* 1977; Sawyer *et al.* 1991; Schlink *et al.* 1994a).

As a herd measure of reproductive performance, average inter-calving interval typically over-represents actual performance as its derivation requires cows to have had two calvings. Therefore, those cows with either poor reproductive performance or who are infertile are not represented in the measure, resulting in an optimistic representation of actual performance (Morton 2010). Additionally, a further major shortcoming of this measure in monitoring overall herd reproductive performance is that first-lactation cows are excluded from the measure as they also have not had two calvings. Within the dairy industry, several methods to adjust herd average calving interval have been used to account for the cows without anticipated or known calving dates and include assigning an arbitrary date of calving, based on either last potential date of conception, inferred from historical information, or a selected high value (Morton 2004). Additionally, dividing the mean calving interval by the proportion of cows within the herd that were not culled for fertility has also been proposed (Plaizier *et al.* 1998). Despite these adjustments improving the estimate of inter-calving interval, in order to compare the reproductive performance of cow herds, knowledge of the rates of culling for infertility is still required to compare the overall herd performance as culling rates are likely to have an economic impact.

The ability of herd managers to use calving interval as the parameter to base management decisions on is limited as calving interval values generally range between 10 to 20 months. Due to this significant lag period before the measure can be derived, calving interval is largely a poor monitoring parameter of reproductive performance. In contrast, the interval between calving to conception has a much smaller lag period associated with its derivation and largely explains calving interval, as greater variation exists for the interval between calving to conception than gestation length. The proportion of cows pregnant by a specified time from calving has also been used as a parameter to monitor reproductive performance (Morton 2004).

A commonly expressed objective for reproductive performance in beef cattle is for each cow to contribute a calf each year. Therefore, assuming a 283 day average gestation length, to achieve this objective cows must become pregnant within approximately 82 days of calving. However, following a review of the literature, measures of reproductive performance in beef cattle herds describing the proportion of cows which become pregnant within approximately 80 days from calving were not identified. In contrast, the proportion of cows which become pregnant by various time periods since calving have been used to describe reproductive performance in the dairy industry; 60 days post-partum (Pursley *et al.* 1997), 80 days post-partum (Uchida *et al.* 2001), 100 days post-partum (Pursley *et al.* 1997; Morton 2004) and 115 days post-partum (Ferguson 1996).

2.4.5 Measures of reproductive loss

Overall improvements in reproductive performance from increases in rates of pregnancy can only be realised if the pregnancy is maintained until full term and the calf successfully reared until branding or weaning. Measurement of reproductive loss is required to quantify its impact on the overall herd performance. The proportion of confirmed pregnant heifers and cows that fail to contribute a calf has been used to describe reproductive performance and relates specifically to the period of the annual production cycle between pregnancy diagnosis and branding or weaning (Coates and Mannetje 1990; Sullivan and O'Rourke 1997; Schatz and Hearnden 2008).

Pre-natal mortality is defined as foetal losses occurring between day 45 of gestation and parturition (Committee on Bovine Reproductive Nomenclature 1972) whilst peri-natal, within 2 days of birth, and post-natal, between 2 days of birth and weaning (Holroyd 1987). In some intensively monitored research studies, the timing when foetal or calf losses occur are specifically identified using measures of pre-, peri- and post-natal losses and are presented as a percentage of the maintained pregnancies at the start of the relevant time period (Burns *et al.* 2010). However, when monitoring reproductive performance within commercial beef enterprises, the routine determination of when abortions or mortalities occur is not possible as only one pregnancy diagnosis is typically performed between mating and calving, and calves are not closely observed until weaning. Thus, total losses from confirmed pregnancy to weaning are typically reported.

Measures of peri- and post-natal mortalities have been used in northern Australia research studies with identification of newly born calves and their dams, and subsequent close observation (Holroyd 1987). Such intensity of management is not practical in commercial beef enterprises. Alternatively, where heifers and cows are individually identified, foetal and calf loss is inferred by confirmed pregnant heifers and cows failing to be observed as lactating after their expected calving date (Schatz and Hearnden 2008). Under commercial conditions lactation failure rates are derived following a visual assessment of lactation status, or the udder stripped in less obvious cases. Associated errors and therefore errors in rates of foetal and calf losses derived from this method were not identified in searches of the literature. However, it is speculated that visual assessments of lactation assessment has moderate to high sensitivity and specificity with errors likely to be associated with stage of lactation, assessor, facilities and treatment of cattle prior to assessment.

In the absence of individual identification of heifers and cows measures of foetal and calf loss have been inferred by the discrepancy between branding or weaning rates and pregnancy percentages (Holroyd *et al.* 1979a). The precision of such methods is questionable under conditions that do not limit the uncontrolled movement of cattle or adequate records of cattle movements are not documented.

2.4.6 Calving, Branding and Weaning rate

Reproductive performance measures describing the proportion of mated breeding females that rear a calf to either branding or weaning are well established and extensively used within the north Australian beef industry and are commonly referred to as branding and weaning rate or percentage, respectively. Calving rate is the number of calves born (dead or alive) as a proportion of the cows mated in the previous year and is typically expressed as a percentage, which is less commonly used within the northern Australia beef industry due to the impracticality of its determination under the extensive conditions common for northern Australia. Whilst, both branding and weaning percentage are effective as an overall reproductive measure they typically represent a timeframe of 15-18 months or greater (ie from mating to branding or weaning), which causes inaccuracy of their measure due to the inability to accurately record heifer and cow numbers since mating in the previous year. Future more, both annual branding and weaning rates represent the overall reproductive performance of a beef breeding herd as they evaluate conception, pregnancy, calving, and pre-weaning success or failure. However, their ability to identify areas of underperformance is limited as differences between conception rates and foetal/calf losses to either branding or weaning are indistinguishable.

Various methods to derive annual branding and weaning rates have resulted from attempts being made to account for the various herd management choices applied between mating and either branding or weaning (the timeframe for which the outcome of interest represents), such as removal of culls and addition of replacement females. These variations in method, such as dividing the number of weaners by number of breeding females mustered rather than previously mated (ie excludes those cows culled for non-pregnancy and mortality of cows), make comparisons between herds difficult and their interpretation often misleading and confusing. Additional, complexities arise with the derivation of either branding or weaning rate due to difficulties in accounting for the uncontrolled movement of cattle in some areas of northern Australia.

2.4.7 Including weaner information

Productivity indicators describing the average weight weaned per exposed female are used across many livestock production industries including beef cattle within Australia (Arthur *et al.* 1999), and internationally (López de Torre *et al.* 1992; Franke *et al.* 2001). This metric provides an indication of the overall reproductive productivity of an animal or management group and combines efficiency of cows which become pregnant, foetal/foetal calf loss, and calf performance into one measure. One particular strength of this index is that it is dependent on the distribution of calving, as heifers or cows calving earlier in the calving season typically wean heavier calves (Marshall *et al.* 1990) and additionally, allows herd managers to quantify trade-offs on a herd level between the reproductive performance of heifers or cows and growth characteristics of progeny. Adjustment for the average liveweight of heifers or cows mated has also been used, including per 1 kg of cow mated (Hunt *et al.* 2013), per 100kg cow mated (Cobiac 2006) or per animal equivalent (McCosker and Cobiac 2008). Efficiency measures, such as these are not commonly used within commercial Northern Australia beef enterprises as they require the collection of liveweight data for weaned progeny and potentially mated cows, which is not routinely collected.

For similar reasons to those previously discussed in relation to branding and weaning percentage, a complexity of applying this measure for many commercial north Australian beef enterprises is the limited ability to account for the various management decisions made between mating and weaning in the subsequent year and the further complication of uncontrolled movement of cattle in much of northern Australia. Therefore, basing a comparison of performance using this measure across herds requires careful consideration and the collection of rigorous data.

2.5 Reproductive performance of beef cattle in northern Australia

There is no national monitoring of reproductive performance in beef cattle herds in Australia. Within research activities undertaken in northern Australia, no studies have reported descriptive statistics for reproductive performances using a random selection of commercial beef herds. However, one study has described observed reproductive performances in commercial beef heifer and first-lactation cow management groups for multiple herds within the Northern Territory (Schatz and Hearnden 2008).

The literature describing the reproductive efficiency of north Australian beef cattle has been recently summarised by Burns *et al.* (2010). Typical levels of reproductive performance for commercial north Australian beef herds are generally described using two major sources, performances measured during specific research activities on both commercial properties and research facilities (Burns *et al.* 2010) and perceived estimates made by herd managers captured during surveys (O'Rourke *et al.* 1992; Bortolussi *et al.* 2005a). This highlights a significant limitation of the literature, as the representativeness of reproductive performance estimates based on research activities to actual performance within commercial industry is unknown. Alternatively, levels of reproductive performance determined by survey are also likely to be over-estimates given there is often discrepancy between perceived performance levels and those occurring in reality as demonstrated by Schatz and Hearnden (2008) who measured a much lower reproductive rate to that reported by herd managers in an extensive face to face survey.

2.5.1 Pregnancy

For more extensively managed parts of northern Australia whole herd pregnancy diagnosis is less common (Bortolussi *et al.* 2005a). In the recently completed Northern Territory pastoral industry survey, only approximately half of the respondents conducted whole herd pregnancy diagnosis within the Barkly and Top End districts (Cowley *et al.* 2014). Hence, knowledge of commercial levels of performance for annual pregnancy percentage is limited. Reviews of reproductive performance for beef cattle in research studies relevant to northern Australia have been reported by Entwistle (1983) and Burns *et al.* (2010). This research is relevant to the definition of typical and realistically achievable levels of pregnancy in northern Australia beef cattle. Research results relevant to assessing the impact of selected factors on the probability of pregnancy are reviewed in subsequent sections of this chapter.

Large variation exists for pregnancy percentages observed throughout northern Australia. Performances reviewed by Entwistle (1983) documented ranges between approximately 20% for some groups to exceeding 90% in others, which were later reaffirmed twenty-seven years later by Burns *et al.* (2010). Whilst, one potential interpretation of these results is that there has been only limited improvement in the overall annual pregnancy percentage. It can be equally postulated that improvements in reproductive productivity have occurred although these improvements are not detectable using the measure annual pregnancy percentage. For example, it is not unlikely that even though pregnancy percentages have been maintained, average weaner weights have increased through reduced spread of calving as a result of improvements in herd management practices such as weaning, supplementation, and bull management. Thus, improvement in the overall herd productivity has occurred. Nonetheless, the evident wide range in reproductive rates suggests that the prevalence of exposure to important risk factors varies between herds, which is significant for the research concerned and implies scope for improvement.

A commonly expressed objective for beef cattle reproductive performance is a calf for each cow mated each year. This objective is potentially nonsensical for beef production enterprises within more extensive parts of northern Australia and some attempts have been made to set objective performance goals relevant to beef herds in northern Australia. Computationally, an overall annual pregnancy percentage of approximately 90% has been suggested as an achievable level of performance. Hasker (2000) suggested a realistic goal of 80 weaners per 100 exposed females, while Holroyd (1987) suggests an 'accepted level' of foetal and calf mortality in the order of 12%. Using data published since 1990 and defining an achievable level of performance as the 75th percentile, annual pregnancy percentages of 87%, 54% and 90% are potential achievable levels of performance for heifer, first-lactation cow and mature cow groups within northern beef herds, respectively (Burns 1990; Hasker 2000; Schatz and Hearnden 2008). Whilst, typical levels of performance for annual pregnancy percentages are 84%, 17%, and 81% when defined as the median value for heifer, first-lactation cow and mature cow groups within northern beef herds, respectively (Burns 1990; Hasker 2000; Schatz and Hearnden 2008).

An identified limitation of the literature relevant to northern Australia beef production is minimal studies have described pregnancy based on time of event data such as percentage pregnant within cut-points in time since either calving or mating start date. In those cases where time to event outcome measures were of interest, inter-calving interval has been the outcome measure of choice which particularly, when summarised using the arithmetic mean, is known to have significant limitations (Morton 2010). Two studies completed within the Northern Territory however have described the proportion of cows having inter-calving intervals less than or equal to 12 months and therefore equivalent to confirmed pregnant within approximately 2.5 months or 80 days after calving. In mixed aged *B. indicus* cows located within the western gulf region of the Northern Territory, Schlink *et al.* (1994b) reported a 4-year average of 22.7% of cows having inter-calving intervals less than or equal to 12 months. While, Hunt *et al.* (2013) reported between 21-28% of management groups having inter-calving intervals less than or equal to 12 months for mixed age *B. indicus* cows grazing under different pasture utilisation rates within the Victoria River District.

A strong association exists between prolonged periods of post-partum anoestrus and low probability of pregnancy within northern Australia (Entwistle 1983; Montiel and Ahuja 2005). By its influence both on annual pregnancy percentage and the average liveweight of calves at weaning, percentage of lactating cows pregnant is an indicator of overall reproductive productivity. Using research data describing pregnancy percentages in lactating cows within northern Australia published since 1990, achievable level of performances, defined as the 75th percentile, were 54% and 61% for first-lactation and mixed mature cows, respectively while typical (median) performances were 17% and 36%, respectively.

2.5.2 Confirmed pregnancy to weaning loss

Foetal and calf mortalities are an important cause of reproductive wastage for north Australian beef herds and are considerable and highly variable. An average prevalence of foetal and calf mortality under ideal north Australian situations is estimated at 9% (Fordyce *et al.* 2005) and often being documented as exceeding 30% within research studies. An 'economically tolerable' limit for foetal and calf mortality in north Australian beef herds has been suggested by Holroyd (1987) as 12% when reproductive diseases are controlled. Drawing on data from research studies completed since 1990 relevant to northern Australia, an achievable level of foetal and calf loss, defined as the 25% percentile, were 12% and 8% for first-lactation and mature cows, respectively (Schatz and Hearnden 2008; Burns *et al.* 2010; Bunter *et al.* 2013). Whilst, typical levels of foetal and calf loss, defined as the median value, were 21% and 14%, respectively.

Few studies have determined the stage of foetal and calf losses in commercial beef herds within northern Australia, as under extensive conditions only total losses from confirmed pregnancy to weaning can be studied. An extensive review of the literature relevant to northern Australia has been completed by Burns *et al.* (2010) who reported pre-natal, peri-natal and post-natal losses ranging from 1-17, 2-12 and 1-15%, respectively and suggested acceptable levels of loss for each of these categories were 3%, 5% and 1%, respectively and therefore, 9% loss between confirmed pregnancy to weaning.

Foetal and calf mortalities are difficult to quantify within commercial extensively managed herds and correspondingly herd managers vary in confidence regarding estimates of calf mortality. In a recently completed survey within the Northern Territory, only 31% of herd managers surveyed, provided a response to estimates of calf loss within their herd and of those 10% had a high degree of confidence in their response (Cowley *et al.* 2014). By method of survey, the average estimated calf loss across the Top End, Katherine and Barkly regions were 3%, 11% and 14%, respectively (Cowley *et al.* 2014).

In contrast with foetal and calf mortality, fertilisation failure and embryonic mortality are considered to be much lesser causes of reproductive wastage for north Australian beef herds (Entwistle 1983). Additionally, females which suffer from either fertilisation failure or embryonic mortality are often thought of reconceiving within the same mating period (Fordyce *et al.* 2005) and therefore, potentially still contribute a calf of reduced liveweight at weaning.

2.5.3 Branding and Weaning rate

Annual branding and weaning rate are the measures of reproductive performance with which herd managers are most familiar and are those that are commonly used to monitor reproductive performance. By method of industry survey, perceived estimates held by herd managers for reproductive performance of commercial herds has been captured by O'Rourke *et al.* (1992); Bortolussi *et al.* (2005a) and Cowley *et al.* (2014). Hasker (2000) suggested a realistic objective for annual weaning rate was 80%, which when considered in relation to estimates of commercial performances captured by survey would suggest that the majority of herds within northern Australia have considerable scope for improvement. Using data derived from the 2002-12 ABARES annual Australian Agricultural and Grazing Industries Surveys, Martin *et al.* (2013) reported an overall average annual branding rate of 71% for commercial beef enterprises within northern Australia. Bortolussi *et al.* (2005a) documented median 5-year (1991-1995) average branding rates varying between 63-78% across regions of northern Australia using data derived from 335 beef cattle enterprises throughout northern Australia. Similar performances were reported in a survey of Queensland beef enterprises conducted during 1990 with the average branding rate of 63.2% being reported (O'Rourke *et al.* 1992).

In an extensive survey completed across northern Australia, large differences in annual branding rates was documented, with a range of 40-50 percentage points typical for regional survey groups (Bortolussi *et al.* 2005a). With respect to the interest of the current research, this clearly demonstrates the population variance for reproductive performance and potentially signifies that the prevalence rates of important risk factors vary between herds. By employing existing epidemiological research techniques the relative importance of risk factors in explaining this variation can potentially be ascertained.

2.6 Effects of selected risk factors on reproductive performance of beef cattle

Demonstrated impacts of a multitude of factors on the reproductive performance of beef cows are encompassed within the scientific literature. Although significant breath on impacts of risk factors on reproductive performance of cattle is contained within the scientific literature, this review will summarise the reported effects of selected risk factors on reproductive performance of beef cows within northern Australia. This review focused on the effects of risk factors on measures of reproductive performance such as pregnancy percentage, pregnancy to weaning loss or branding and weaning rate. The selected risk factors considered in this review can be classed as relating to environment, nutrition, management, infectious disease or genotype/phenotype and are presented according to which they concern.

2.6.1 Environmental influences

2.6.1.1 Region

The rangelands of northern Australia have been categorised into areas of similar land, soil type and vegetation and pasture communities they support (Tothill and Gillies 1992). Biophysical characteristics for significant regions and pasture communities for beef cattle production within northern Australia are discussed in more detail in Section 2.2. Within northern Australia, no population-based studies have been conducted to quantify the direct or moderating effects of 'region'. However, risk factors describing 'region' have previously been identified as significant predictor variables for the reproductive performance of cattle internationally (McFadden *et al.* 2005).

Differences in animal productivity between pasture communities and regions within northern Australia are described in the literature (O'Rourke *et al.* 1992; Bortolussi *et al.* 2005a; Bortolussi *et al.* 2005c; Gleeson *et al.* 2012) using estimated performances born from surveying herd managers and owners. There is increased prevalence of lower pregnancy percentages and elevated losses between confirmed pregnancy and weaning for breeding groups within northern regions relative to those in southern parts of northern Australia (Entwistle 1983) ABARES annual Australian Agricultural and Grazing Industries Survey data suggests differences in branding rates in the order of 20-30 percentage points (Figure 2-5) (Gleeson *et al.* 2012).

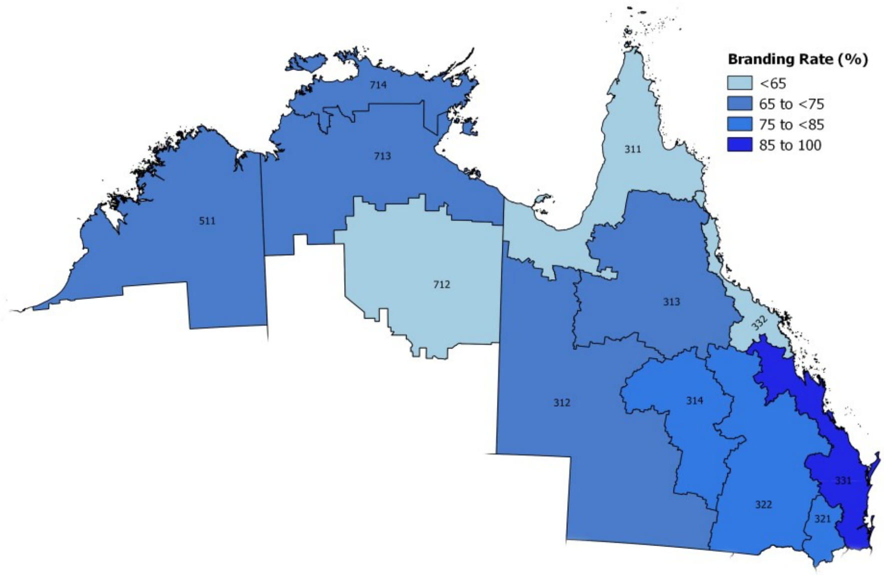

Figure 2-5. Average branding rate of farm businesses for Australian Bureau of Statistics statistical regions (adapted from Gleeson et al. 2012).

Reproductive performances observed during research studies conducted within northern Australia have been collated by Entwistle (1983); Holroyd and O'Rourke (1989); Hasker (2000) and Burns *et al.* (2010) which highlight significant variation and overlap for ranges of reproductive performance between areas of significance in terms of beef cattle production. Greatest variability for herd pregnancy percentages is specified for the tropical tallgrass pastured areas of northern Queensland and Northern Territory, while whole herd and wet-cow pregnancy percentages were generally lowest within this region with values ranging between 20-86% and 0-96%, respectively. Contrastingly, annual pregnancy percentages generally exceeded 70% for remaining areas of northern Australia. Annual pregnancy percentages within Mitchell grassed pastures of central Northern Territory and western Queensland and central eastern and southern areas of Queensland including brigalow (*Acacia harpophylla*) vegetation were similar in range with 79-96% and 71-96%, respectively. Pregnancy percentages for lactating cows within Mitchell grass pastured areas ranged between 41-97%. In speargrass and mixed forest areas of southern Queensland herd pregnancy percentages ranged between 61-97%, which is also likely to largely reflect pregnancy percentages for lactating cows as non-lactating cows are generally culled prior to pregnancy diagnosis for the majority of enterprises within this region (Bortolussi *et al.* 2005a).

Confirmed pregnancy to weaning loss of approximately 10% is normal for tropical tallgrass pastured areas with mortality rates exceeding 30% not an uncommon occurrence (Schatz and Hearnden 2008; Burns *et al.* 2010). Schatz and Hearnden (2008) documented similar confirmed pregnancy to weaning loss in first-lactation cows grazing Mitchell grass pastured areas of Northern Territory, which ranged between 10-39%. Less frequent extreme values for losses between confirmed pregnancy to weaning were evident in Brigalow vegetated areas of Queensland when compared to northern regions with values ranging between 7-18%. On three research stations located within southern and central parts of Queensland, calf mortality rates of less than 10% were observed across 9 years of observation for closely monitored tropical composite and Brahman breeding herds (Bunter *et al.* 2013).

In summary, differences in animal productivity between regions within northern Australia have been described and are largely based on values derived from survey or from specific research projects conducted on research facilities or commercial properties. Whilst these values have identified substantial differences in performance, an identified limitation of the literature is that the external validity of these estimates is uncertain as the study populations may not be reflective of the broader north Australian beef cattle population and the impact of region or country has not been quantified after the portioning of effects for other extraneous factors that are likely to confound the observed association.

2.6.1.2 Seasonal Variation

Rainfall is undoubtedly the major driver of ecological processes within rangelands, which in tropical parts of northern Australia is highly seasonal, with 90% of the annual rainfall falling between November and April during the ‘wet’ or ‘monsoon season’ (Nicholls *et al.* 1982). The timing, amount, and intensity of rain are highly variable between years, which have pronounced effects on the nutritional quality, composition and available biomass of pastures. As north Australian beef herds predominantly graze native, naturalised or improved pastures their nutritional plane and productivity is therefore ultimately determined by amount and pattern of rainfall. O'Rourke (1994) suggested the timing of onset and conclusion, and pattern of rainfall for the wet season were critical drivers for the length and severity of the dry season, and key determinants for animal productivity.

Numerous studies have reported the dominating influence of seasonal influences on reproductive performance in beef cattle herds in northern Australia (Holroyd and O'Rourke 1989). Consequently, it has been suggested that ecological studies conducted within the northern regions of northern Australia should continue for 6-8 years (Taylor and Tulloch 1985). The factors associated with the effect of season on fertility are suggested to include negative energy balance around the time of calving (Lalman *et al.* 1997; Schatz and Hearnden 2008; Waldner and García Guerra 2013), body condition (Fordyce *et al.* 1990; Vargas *et al.* 1999; Blanc and Agabriel 2008), heat stress (Turner 1982) and potentially other unexplained nutritional parameters (Frisch *et al.* 1987).

The factors strongly associated with loss between confirmed pregnancy and weaning remain largely 'undetermined' with the effect of season inconsistent. Despite this, where there is an associated effect of calving season, factors that are suggested to be associated with calf loss include heat stress (Brown *et al.* 2003; Fordyce *et al.* 2015), vitamin A deficiency after consecutive low-rainfall years on treeless plains (Holroyd *et al.* 2005) and factors indirectly associated by their influence on birth weight (Bunter *et al.* 2013) or milk yield including body condition score and nutritional parameters around the time of calving (Edye *et al.* 1972).

Extreme naturally occurring events such as flooding and cyclones are also thought to negatively impact reproductive performance and cause variation in performance across years. Due to the cyclical nature of endemic diseases and therefore, varying levels of herd immunity and exposure to endemic reproductive diseases in unvaccinated herds across time, inter-year variation in reproductive performance for some beef herds may be partly contribute to endemic reproductive disease epidemics.

A study that was conducted in central Queensland during 1957-1984 observed large random fluctuations in annual calving rate(Mackinnon *et al.* 1989). Differences in calving rate exceeding 30% between some years were observed however, generally differences of 5-10 percentage points were mostly observed (Mackinnon *et al.* 1989). Similarly, a study involving heifers conducted within the Victoria River district of the Northern Territory report statistically significant differences between years for pregnancy percentage and losses between confirmed pregnancy and branding, which ranged between 47-65.5% and 9.4-47.1% across a 4 year period, respectively (Sullivan *et al.* 1997). Alternatively, a research study conducted across a 9 year period and involving five stations located within central and northern Queensland documented an overall average prevalence of calf loss as 9.6%, and most commonly ranging between 1.5% to 16.4% across sites and seasons.

Although, the associated effects of season appeared to be modified by site as an unusually high value of 41.0% was observed in one year at one site whilst, season was determined to be not statistically associated with the prevalence of calf loss at another location (Bunter *et al.* 2013).

2.6.1.3 Heat stress

Large areas of northern Australia are characterised as tropical and subtropical, which are subject to extended periods of high ambient temperature and relative humidity. Under such conditions cattle cannot effectively dissipate heat using either non-evaporative or evaporative methods leading to a rise in body temperature. Research studies, predominantly involving dairy cows, have documented the negative effects of heat stress on fertility (Holroyd *et al.* 1993; West 2003; García-Ispierto *et al.* 2006). Under heat stress conditions endocrine changes reduce follicular activity and alter the ovulatory mechanism, leading to a decrease in oocyte and embryo quality. The uterine environment is also modified, reducing the possibility of embryo implantation; increasing the incidence of early foetal loss (García-Ispierto *et al.* 2006). Reduced appetite and dry matter intake are evident in heat stressed cattle, potentially intensifying the negative energy balance of lactating cows and increasing the calving-conception interval.

It has also been suggested conditions inducing heat stress in cattle are associated with increased prevalence of calf mortality due to dehydration (Fordyce *et al.* 2015). This may partially explain the high levels of calf mortality commonly reported for extensively managed cows under extreme tropical conditions (Burns *et al.* 2010). Under periods of thermal stress advanced stages of dehydration are likely in calves due to an overall reduction of milk intake due to a likely reduction in appetite of calves and the reduced milk yields of cows. Under chronic heat stress situations reduced foetal development, resulting in smaller birthweight and vigour following birth (West 2003), which is also known to be associated with reduced calf survival. Under extensively managed situations where watering points are sparse, high temperatures may promote separation of the cow and calf, leading to misadventure or predation.

The effects of the ambient environment on cow performance have been measured using various temperature-humidity indices (THI), which are widely used as an indicator of thermal stress in livestock (Gaughan *et al.* 2008). However, the associated effects of heat stress on reproductive performance of extensively managed north Australian beef herds have not been quantified. Holroyd *et al.* (1993) in a study conducted in north Queensland, reported associations between elevated rectal temperatures and reproductive performance of heifers, however, the magnitude of effect for pregnancy and embryonic mortality was not quantified. In a study conducted in dairy cows located in Spain, García-Ispierto *et al.* (2006) reported a marginal effect of 12% embryonic mortality for cows exposed to THI values exceeding 69 around the time of embryonic implantation. The qualified and quantified effect of thermal stress on calf survival within extensively managed breeding herds of northern Australia is undetermined within the literature.

2.6.1.4 Wild dogs

The wild dog population includes dingoes (*Canis lupus dingo*), feral dogs (*Canis lupus familiaris*) and their hybrids, which occupies all of northern Australia at varying levels of abundance (Figure 2-6). Wild dogs are considered pests due to their recognised involvement in predation, parasite (*Neospora caninum* and *Echinococcus granulosis*) transmission and injury of livestock. Predation of calves by wild dogs has long been recognised with the impact of wild dogs on reproductive performance largely unquantified despite it being of interest to beef cattle stakeholders for a long time. However, there is some conjecture about the actual impact on the beef industry and it has been reported that wild dogs can have positive, neutral (Eldridge *et al.* 2002), negative (Fleming and Korn 1989) and/or variable (Allen 2014) impacts on animal production and the ecosystem. Additionally, there appears to be no correlation between wild dog abundance and predation loss of calves (Allen 2005).

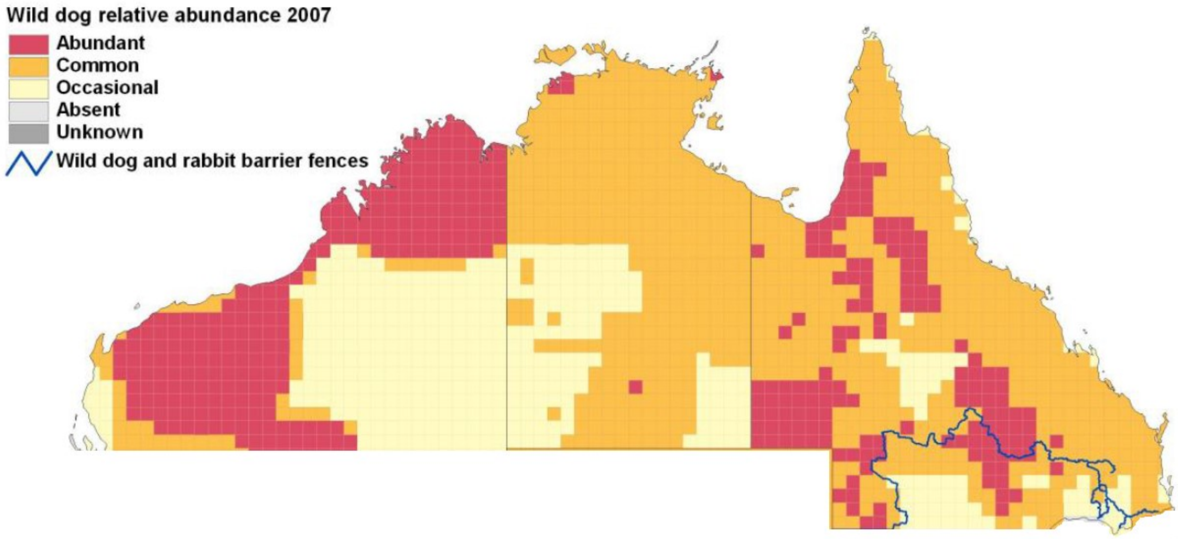

Figure 2-6. Distribution and relative abundance of wild dogs for northern Australia in 2007 (adapted from West 2008)

Prevalence of calf loss caused by wild dogs can be as high as 32% (Rankine and Donaldson 1968; Allen 2005). Although, recent reviews conducted by Hasker (2000) and Burns *et al.* (2010) have not identified wild dogs as a major determinant of reproductive loss. A review conducted by Allen and Fleming (2004) reported a negative correlation between branding rates and calves bitten following the intervention of heightened efforts to control wild dogs. However, alternative findings have been reported in a number of intervention studies investigating differences in reproduction failure rates between non-baited and baited study herds, which have failed to detect statistically significant reductions in calf loss (Eldridge *et al.* 2002). Predation losses were not detected in most years, with losses being observed in those years that appeared to correspond with the limited availability of preferred prey species (Fleming *et al.* 2012). In contrast, increased calf losses or non-fatal attacks have been observed in some cases where baiting had occurred (Eldridge *et al.* 2002; Allen 2014).

Dingoes operate with a strict social system enforced by the dominant pair, who is the only breeding pair of the pack. Under human intervention the pack structure can be disrupted leading to an increase in the number of litters, facilitating a higher abundance of dingoes, and change the age structure of the dingo population with increased proportions of young inexperienced, leaderless individuals, which are more likely to explore for new territories and establishing a dominance hierarchy, thus, increasing the risk of predation of livestock (Glen *et al.* 2007).

These findings highlight the understanding and quantification of the impact of wild dog control measures on predation losses of calves is currently lacking. Additionally, it is of equal importance to quantify factors, particularly environmental and potentially those associated with the frequency, scale and intensity of fire (Anderson *et al.* 2012), associated with availability of prey species and their association with predation loss.

2.6.2 Nutritional risk factors

2.6.2.1 Liveweight, Body condition and energy balance

Nutritional management can have a dramatic effect on the reproductive performance of beef cattle. Liveweight and body condition scoring (BCS) systems can be used to monitor the nutritional management of a herd. Liveweight and BCS are well established reproductive indicators that reflect the energy reserves of an animal, and are available for metabolism, lactation, growth and movement. Mismanagement of cattle by either inappropriate time of weaning, over-utilisation of pasture resources or inadequate treatment of mineral deficiencies can result in cows of low body condition at critical time points. In order to maintain adequate general health, reproductive function, production capacity and survivability satisfactory levels of body energy reserves are required (Fordyce *et al.* 1990).

It is generally well recognised worldwide that BCS and liveweight are major factors influencing the reproductive performance of beef cattle (Entwistle 1983; Fordyce *et al.* 1990; Rae *et al.* 1993; Wettemann *et al.* 2003). The increased energy demands associated with milk production during early lactation often cannot be met by dietary intake and therefore, body reserves are often mobilised under the regulation of several hormones and blood metabolites (Roche *et al.* 2013), which are also considered to regulate ovarian function. Energy is preferentially partitioned towards maintaining basic metabolism, activity, growth and replenishing basic energy reserves over reproductive function such as resumption of cycling and the establishment and maintenance of pregnancy. Therefore, cows in low condition or in a state of negative energy balance are often unable to cycle in early- or during lactation, which has been identified as being the major factor responsible for limited reproductive performance of beef cattle within northern Australia (Entwistle 1983). However, the association between BCS and resumption of cycling are influenced by the dietary nutritional status during early lactating and around the time of calving (Wettemann *et al.* 2003).

Curvilinear and linear relationships between improvement in body condition or liveweight and positive responses in fertility have been demonstrated by numerous research studies (Rae *et al.* 1993; Jolly *et al.* 1996; Dixon 1998; Wettemann *et al.* 2003; Schatz and Hearnden 2008). However an identified limitation of the literature, for northern Australia beef cattle particularly, was that few studies have quantified the effect of BCS on reproductive performance after accounting for other known factors associated with reproductive performance. A study conducted in western Canada determined that the odds of non-pregnancy at BCS ≥7 (using 9 point scale) were not statistically different from the odds of non-pregnancy at BCS=5, when BCS assessed at the pregnancy diagnosis was considered in a multivariable model that included other risk factors including cow age, cow breed type, exposure to a single bull, duration of bull exposure during the breeding season, and month of pregnancy testing (Waldner and García Guerra 2013). In addition, relative to the odds of non-pregnancy at BCS 5 (1-9 scale), Waldner and García Guerra (2013) reported the odds of non-pregnancy was 1.3-1.8 times greater at BCS 4 and 3.5-4.2 times greater at BCS 3 indicating a greater improvement in reproductive performance at lower BCS values. Therefore, it is desirable to have cows in BCS 5 (1 to 9 scale) or 3 (1 to 5 scale) at the time of calving, which is consistent with recommendations by others (Fields and Sand 1993).

Pregnancy percentages for lactating cows in northern Australia were significantly influenced by BCS, with relative to store condition, cows in backward (low) condition -17% and +16% for good condition, respectively (O'Rourke *et al.* 1991a). Associated effects of body condition and with cow mortality and milk production also exist. Although the findings reported for the relationship between BCS and milk yield are variable within beef cattle (Spitzer *et al.* 1995), research studies conducted within dairy herds have established total milk production being positively related to BCS at calving (Roche *et al.* 2009), which is likely to influence calf survival and growth.

In first-lactation cows under commercial management in the Northern Territory, Schatz and Hearnden (2008) using a univariate analysis reported a sigmoidal relationship between liveweight at the first annual muster (weaning) and pregnancy percentage and with the exception of the extremes indicated approximately a 4 percentage point increase in pregnancy percentage per 10 kg increase in liveweight. Similarly, Dixon (1998) estimated a 5 percentage points increase in fertility per 10 kg increase in liveweight for cows less than 340 kg at start of mating and a 3 percentage points for every 10 kg increase for those cows greater than 340 kg liveweight at mating using a dataset derived from beef *Bos indicus* cross cows in northern Australia.

Young cows in low condition have shown lower reproductive performance than mature cows in low condition. A Florida study conducted across 8 herds reported a 70.7 percentage point difference in pregnancy rates between the BCS categories ≤3 and ≥5 for young cows, as opposed to 44.7 percentage point for mature cows (Rae *et al.* 1993). In addition, the reproductive performance of aged cows (>8 years) at lower condition was less than mature cows in lower condition with differences of 10.4 percentage points at BCS ≤3 and 3.2 percentage points at BCS ≥5 (Rae *et al.* 1993).

Within Australia and internationally, BCS is evaluated using different scales but in all cases low values reflect emaciation while high values imply obesity. As there are often logistical difficulties associated with the capture of liveweight including the absence of permanent cattle weighing facilities in many north Australian cattle processing facilities, BCS is often the favoured indicator of body reserves within the commercial industry due to the readiness of its capture. Other advantages for the capture of BCS over liveweight include the ability to assess cattle in a paddock without having to muster and unlike liveweight which is confounded by differences in age, frame size and pregnancy; these factors are accounted for in the evaluation of body condition.

The associated effects of BCS on reproductive performance are predominantly reported in the scientific literature for BCS measured at the time of calving.Fields and Sand (1993) reported similar responses in pregnancy rate for BCS assessed at either calving, breeding or pregnancy testing and indicate a high level of within-animal correlation between BCS observed at different time points for control mated herds. In contrast, BCS measured at pregnancy diagnosis was reported as a stronger predictor of pregnancy than BCS measured at mating start (Waldner and García Guerra 2013), which was speculated to be a result of greater emphasis being placed on cow attendance at pregnancy diagnosis and more complete information being available and reduced error in the assessment of BCS at pregnancy diagnosis as cattle are restrained in a veterinary crush. In a study conducted within northern Queensland, Dixon (1998) reported an association between reproductive performance during the wet season, and body condition at the end of the proceeding dry season.

Under north Australian production systems and environment, in order to achieve the major objective of maintaining body condition at or above BCS 3 (1 to 5 scale) at calving to achieve sound reproductive function (Fields and Sand 1993), minimising the amount of condition lost during the dry season is paramount. A relationship between reducing liveweight loss of non-lactating cows during the dry season by feeding urea-based supplements and increased pregnancy was reported by Dixon (1998) (Figure 2-7).

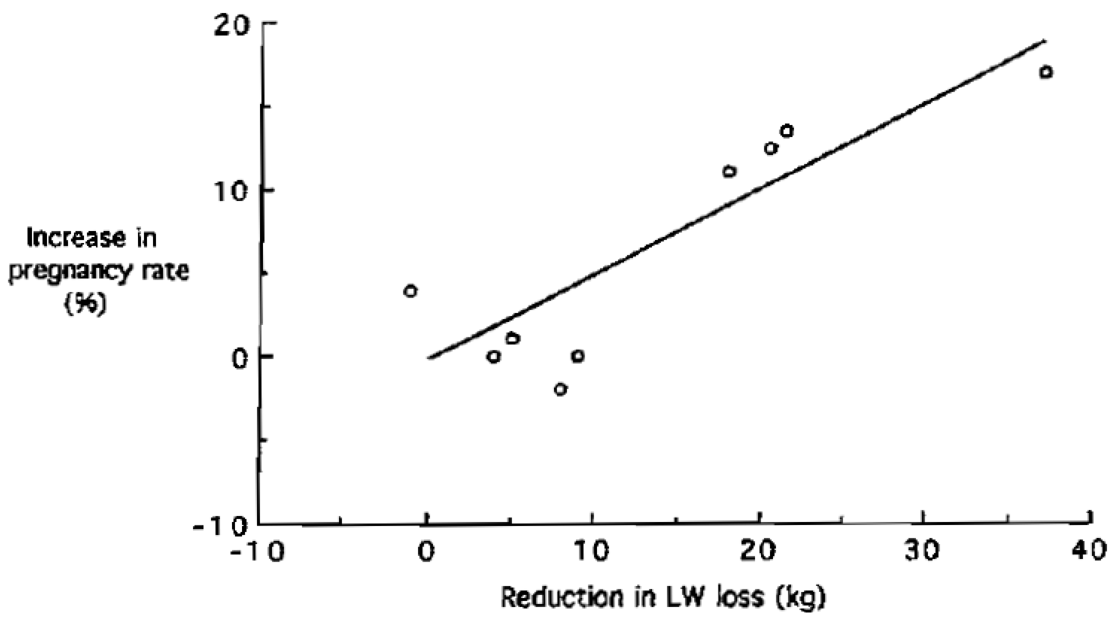

Figure 2-7. Relationship between the reduction in liveweight loss on non-lactating pregnant cows during the dry season and subsequent pregnancy percentage (Dixon 1998).

A number of factors have been identified as affecting the BCS including more productive land types, poorer seasonal conditions (Holroyd *et al.* 1988), reproductive class (Entwistle 1983) and increasing utilisation of pastures (Hunt *et al.* 2013). Management of the land resources is also critical as pasture growth is drastically reduced on land in poor condition compared to that produced from the same land type in good condition (McIvor *et al.* 1995). The management of lactation through timing of calving and weaning to avoid cows lactating during unfavourable times of the year is critical to conserve body condition and promote reproductive performance (Sullivan and O'Rourke 1997).

2.6.2.2 Dietary quality

The north Australian beef industry is based predominantly on utilising native and improved tropical and sub-tropical pastures to provide the basic nutritional requirements of breeding females. The nutritional quality of the sub-tropical and tropical pasture of monsoonal regions of northern Australia declines significantly during the dry season as grasses are generally mature and low in digestibility and crude protein content. Consequently, the nutrients they provide are generally inadequate to meet maintenance requirement, causing loss of body condition and liveweight, and ultimately affecting reproductive performance. Numerous studies assessing the effects of dietary quality on reproductive performance have been completed (Samadi *et al.* 2013), however, no studies were identified that applied statistical adjustment for body condition score, so that the effects of pasture quality and quantity could be estimated independently of body condition score.

The fundamental nutritional drivers of production and reproduction are the dietary intake of digestible dry matter (DMD) and crude protein (CP), which can be estimated using faecal near-infrared reflectance spectroscopy (F.NIRS) based systems (Coates 2000; Dixon and Coates 2005). Studies have demonstrated the intake of pastures of lower digestible dry matter and crude protein result in low body condition at calving and increased interval between parturition and resumption of cycling and reduced fertility (Fordyce *et al.* 1990), particularly for *Bos indicus* cattle (Jolly *et al.* 1995). Similarly, studies demonstrating postpartum cows grazing pastures of approximately 3 units higher for DMD and CP demonstrated early resumption of ovulation (Samadi *et al.* 2013).

DMD is an indicator of the energy in the pasture and represents the energy that is able to be digested and absorbed (Dixon and Coates 2005). The daily dietary energy intake is a function of the amount of pasture available, ie intake is limited when available pastures are limited, and the DMD of the diet. Linear increases in daily intakes have been demonstrated when consuming diets of higher digestibility (CSIRO 2007). Therefore, cattle grazing pastures of higher DMD obtain additional energy both by eating pastures that are more concentrated in energy and due to increased daily intake. The DMD values observed for a seasonally dry tropical environment in north

Queensland ranged between 70% for soon after the break in season during the period of rapid growth and 45% in the late dry season when pastures have senesced (Boval and Dixon 2012). Similar ranges in DMD have been observed for buffel grass (*Cenchrus ciliaris*) pastures of sub-tropical regions of Queensland (Dixon and Coates 2010). The metabolisable energy (ME), which can be predicted from DMD, requirements of animals varies according to the digestibility of the diet, class and physiological state of the animal (CSIRO 2007). The ME requirement of a 400kg animal at maintenance is estimated to be met by grazing pastures of 52% DMD and 54% DMD during lactation, producing 5L of milk per day (Jackson 2012). During pregnancy and lactation cattle will display increased dietary intakes.

CP results represent the protein content of the pasture selected by the animals. The range in CP values estimated for a seasonally dry tropical environment in north Queensland were between 2% and 16% (Boval and Dixon 2012) and for buffel grass pastures between 2-16% (Dixon and Coates 2010). Several studies have investigated the threshold values for when responses to the provision of supplementary protein are likely using various indicators including: pastures containing less than 60 g CP/kg (6%) (Minson 1990); below 1.3 g faecal N/kg (Winks *et al.* 1979); or when the ratio between DMD and CP of pastures are greater than 8-10:1, where at a ratio of 8:1 a response to urea is considered probable and highly likely at 10:1 (Dixon and Coates 2005). While, estimates of pasture quality using F.NIRS indicate that *Bos indicus* and *Bos indicus* cross cattle can gain LW when diet N concentration exceeds about 0.8% (5% CP) (Jackson *et al.* 2012).

Studies assessing the impact of different threshold values for the ratio DMD:CP on reproductive performance of beef cattle could not be identified within the literature. However, responses to supplemental N during the dry season in pastures containing less than 6-8% protein have been demonstrated (Fordyce *et al.* 1997; Dixon 1998). For first-calf 50% *B indicus* content heifers in north Queensland supplemental N during the dry season generated up to a 15 percentage point increase in pregnancy percentage (Dixon 1998). The provision of supplemental N during the dry season is generally widely practiced however, during the wet season supplemental N is not provided as P is generally considered to be the most limiting nutrient. There are logistical issues associated with the distribution of supplement during the wet season and risk of urea toxicity due to its high solubility characteristics. However, studies providing protein during the wet season have demonstrated improvements in pregnancy percentages and reductions in mortality rate and losses between pregnancy diagnosis and weaning McCosker *et al.* (1991). Similar to other studies investigating the effects of protein and energy, statistical methods accounting for the differences in liveweight and body condition were not applied so that the effects of providing supplemental N during the wet season could be considered independent of the associated effects of improving liveweight.

2.6.2.3 Phosphorus

Phosphorus (P) is a key factor in animal production in northern Australia (Miller *et al.* 1990). Breeding cattle continuously grazing P deficient pastures have generally shown poorer than expected reproductive performance although, responses in reproductive performance from the supplementation of P have been inconsistent (Underwood and Suttle 1999). For cattle grazing low P diets, a P deficiency is likely to occur when energy and protein increase over the wet season, late pregnancy and lactation unless additional P is supplied (Jones 1990). The confusion surrounding the impact of P nutrition on the performance of grazing cattle has mostly arisen due to the animal's ability to mobilise skeletal reserves when dietary P is inadequate, and the detrimental effect of P deficiency on feed intake. Additionally, as P is generally the third most limiting nutrient after energy and protein, and responses to P have been inconsistent due to the limitation of these components rather than P. However, cattle grazing P deficient situations can develop signs of aphosphorosis such as reduced appetite, growth rate, reproductive performance and milk yield, bone abnormalities, and stiffened gait (also known as 'peg leg') (Winks 1990). Where responses from the supplementation of P have occurred it is uncertain as to whether the responses are due to the direct result of P itself or are simply due to increased feed intake (Karn 2001). A P deficiency induced reduction in feed intake reduced LWG of cattle in individual pens (Bortolussi et al., 1996) and grazing tropical forages on P deficient soils across northern Australia (Winter *et al.* 1990).

The majority of studies which have reported responses in reproductive performance from P supplementation have been conducted overseas, particularly in South Africa. Few Australian studies have reported improvements in reproductive performance from the supplementation of P. Over an 8 year period, Holroyd *et al.* (1977) and Holroyd *et al.* (1983) reported improvements in conception rates of young cows grazing native pastures in coastal North Queensland that were supplemented with P during the wet season. In young cows being supplemented with molasses throughout the year, Holroyd *et al.* (1977) observed a 25 percentage point difference in pregnancy percentage between cows supplemented and not supplemented with P during the wet season. A difference of 22.7 percentage points was observed the following year, however, in the third year a difference of only 3.4 percentage points was reported. The reduced response in older animals possibly is due to the reduced requirement of P for growth and therefore greater body reserves. Reproductive responses from the supplementation of P have also been documented in the Charters Towers' region

(Winks 1990). Hart and Michell (1965) reported that the supplementation of P appeared to improve the pregnancy percentages of lactating cows in a study conducted on the Barkly Tableland. However, Quigley *et al.* (2015) failed to demonstrate responses in annual pregnancy percentage or weaning rate from the provision of P during the wet or dry season within the Barkly Tableland. Dixon *et al.* (1996) failed to show a response in conception rates with first and second calf cows that were supplemented with P during the wet season (59% not supplemented vs. 62% supplemented). Cohen (1976) also was not able to show a response to P in cattle grazing a carpet grass (*Axonopus affinis*) pasture in Grafton.

Lactating animals deficient in P have reduced milk yields (Underwood and Suttle 1999) and the consumption of milk accounts for a significant proportion of the growth rate of calves (Neville 1962; Holroyd *et al.* 1979b). However, responses in weight of calves at weaning from the supplementation of cows with P have again been inconsistent. Cows grazing native pasture and supplemented with 227 g/hd/d of molasses at Swan's Lagoon, were reported not to show a significant response in daily milk yield (4.06 vs. 4.35 kg) or weaner weights (143.0 kg vs. 149.8 kg) to the supplementation of P during the wet season (Holroyd *et al.* 1979a). Allan *et al.* (1972) reported an increase in daily milk yield from the wet season P supplementation of first-lactation cows P at Swan's Lagoon (coastal north Queensland) (not supplemented 4.10 kg vs. supplemented 4.57 kg), but unfortunately did not report the effects on weaning weight. Where responses have occurred it is unclear whether the response is directly related to increased P supply or increased dry matter intake.

No studies were identified within the literature reporting associations with adequacy of P and foetal/calf loss. However, indirectly through reduced milk supply, calves born to cows deficient in P are likely to be of increased risk of dehydration and subsequent mortality within northern Australia as described by Fordyce *et al.* (2015). Quigley *et al.* (2015) failed to detect differences in foetal/calf loss from the provision of P during either the wet or dry season within the Barkly Tableland, however, responses in growing cattle were also not observed within this study suggesting that cattle were not consuming a diet of low P with adequate metabolisable energy and crude protein.

North Australian soils are low to very low in available P. Soil P concentration has been shown to be correlated to plant P concentration (Kerridge *et al.* 1990) and dietary P intake (McLean *et al.* 1990). In a study comparing the soil P of four sites across northern Australia Kerridge *et al.* (1990) demonstrated that bicarbonate extractable soil P was related to animal performance. Over much of northern Australia the soils, and hence, forages are acutely deficient (<5 ppm P in soil) (Quigley *et al.* 2015) as illustrated in Figure 2-8 (McCosker and Winks 1994).

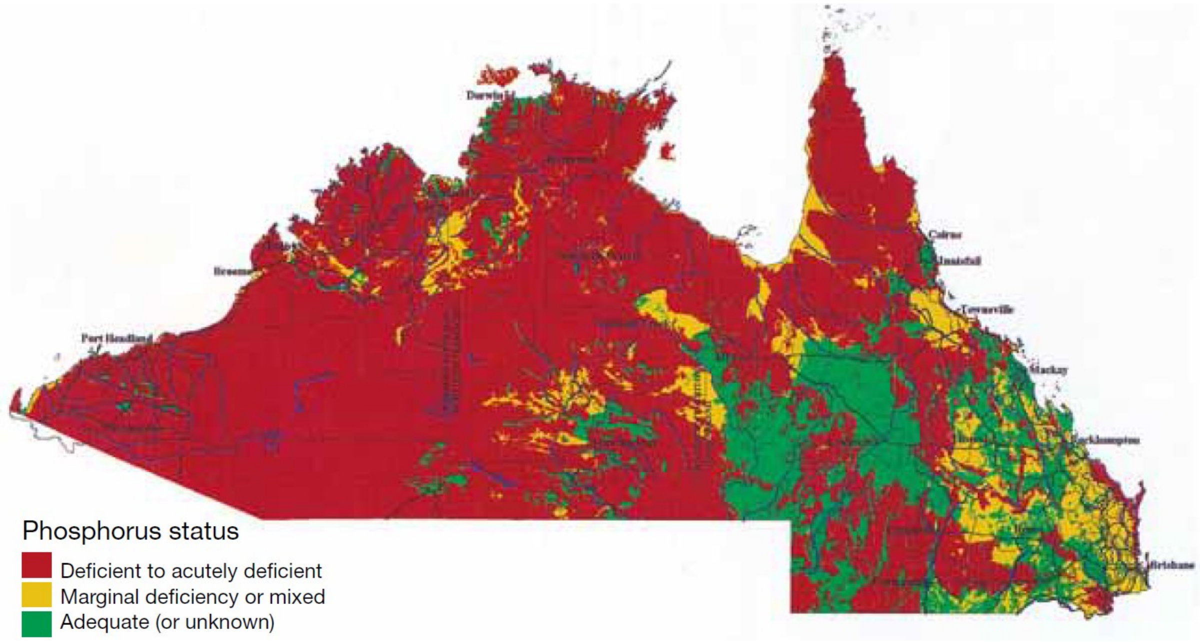

Figure 2-8: Map showing general extent of phosphorus deficiency over northern Australia (McCosker and Winks 1994)

Soil P as an indicator of P status at a paddock/ management group-level is limited as significant variation exists over small distances and therefore, grazing areas of greater than a few square kilometres may contain areas of soils and vegetation of higher P than the level defined from soil mapping (Miller *et al.* 1990). Therefore, to accurately define the average soil P of a paddock you need the results of a cross-sectional sampling. Forage P has been suggested as a possible method of indicating dietary P intake however, there is known limitations of this method. The P status of forages varies widely and is dependent on the P status of the soil, the maturity of the plant and the climate (Underwood and Suttle 1999). Further, it is very difficult to collect samples as selectively as animals graze (Cohen 1973). The ability of grazing animals to select herbage of high P concentration that present in the standing sward has been long recognised (Ganskopp *et al.* 1997). The use of fistulated animals to represent dietary intake also has limitations as extrusa samples may be contaminated by saliva P. Blood P has been found to be a good indicator of deficient to normal dietary P levels. At higher P intakes, blood P has limited application due to the reduced coefficient of absorption and the increased urinary losses when P is supplied in excess (Ternouth 1990). Estimates of inorganic plasma P (Pi) are therefore useful to indicate the immediate level of P intake. Measurement of Pi has been shown to be useful to indicate immediate P intake and also in P supplemented cattle (Quigley *et al.* 2015). Sample preparation has also been shown to influence reported P levels. If prepared incorrectly, organic phosphate compounds can be broken down resulting in false high readings being reported.

Compositional analysis of faeces provides a good indication of pasture composition. Faecal P has been used as an indicator of diet P. Faecal P levels less than 0.2% have been suggested to be indicative of risk of development of clinical P deficiency (Moir 1966) with responses to P supplementation occurring at faecal P concentrations of 0.3% (Winter 1988) and 0.4% (Winks *et al.* 1977). As an indicator of whether the dietary P concentration is sufficient to meet the current P requirements, the ratio of the concentration of P in faecal DM to concentration of ME in the diet ingested (mg faecal P/MJME; FP:ME) has been used (Jackson *et al.* 2012). However, its derivation when supplements are fed is considered to potentially introduce error (Jackson 2012). Quigley *et al.* (2015) validated that FP:ME will provide an indication of dietary P content of the diet. However, this measure is less likely to provide an indication of the immediate intake of P although, its relationship improves with increasing time animals consume the diet. Threshold indicator values for lactating 400 kg cows range between 390-460 mg faecal P per MJ ME for a range of LW gains (Jackson 2012).

In conclusion, accurately measuring P intake of grazing cattle and determining dietary P concentrations is not possible using current technology. Therefore, to estimate the risk of P deficiency affecting the reproductive performance of breeding females a couple of indicators must be used. Soil P maps have their application at a regional and property scale. However, due to the large spatial variation that occurs over small distances its limitation is at a small scale. Faecal P has been shown to be an inaccurate indicator of the P status of individual animals over small time frames, however, using the faecal P to metabolisable energy ratio to estimate the amount of dietary P available is likely to provide a useful management group-level measure of P status.

2.6.3 Genotypic and phenotypic effects

2.6.3.1 Class of Animal

The reduced pregnancy percentage and increased prevalence of foetal and calf losses for first-lactation cows in comparison to that of mature and aged cows has been reported extensively. The biological mechanism for the effect of age on pregnancy appears to relate to the partitioning of energy towards growth as well as reproduction (Entwistle 1983). The reduced supply of energy during reproductive processes is widely accepted to affect folliculogenesis and delay ovulation

(Scaramuzzi *et al.* 2011). This is potentially exacerbated for *B indicus* cattle as they are generally considered to be later maturing (Freetly *et al.* 2011) and located in less nutritionally endowed areas. The majority of growth for cows occurs within 4.5 years of age when they mature skeletally (Fordyce *et al.* 2013a).

The mechanism that age affects foetal and calf losses is more uncertain however, misadventure and mismothering was ascribed as accounting for 38% of foetal and calf losses in an observational study conducted on first-lactation cows on the Barkly tablelands, Northern Territory (Brown *et al.* 2003) and due to learnt maternal instincts the prevalence of mismothering is considered to reduce with parity (Schatz 2011; Bunter *et al.* 2013).

Associations between animal class or parity and reproductive performance have been reported using data generated by survey method or by expemental studies conducted on either Research facilities or commercial enterprises. However, a small number of studies have been designed to assess the effects of age or parity independent of other major predictors of pregnancy and foetal/calf loss. No studies were located within the literature that applied statistical methods to quantify the effect of parity independent of the effects of month or period of calving in the previous reproductive cycle. However, after accounting for effects associated with BCS, breed type and duration of mating, the association of 'Age Category' and risk of non-pregnancy was statistically significant with aged cows (>10 years) and first-lactation cows less likely to achieve pregnancy than cows between 3-9 years of age (Waldner and García Guerra 2013). Across two breeding seasons the odds ratio, relational to the odds of non-pregnancy for mature cows approximately 4-9 years, for heifers ranged between 1.1-2.79 and 1.81-2.28 aged cows; >10years. Using a similar statistical approach in a large observational study conducted across Canada, the odds of abortion in heifers and cows >10 years of age were 1.5 (95% CI 1.17-2.08) and 1.55 (95% CI 1.01-2.38), respectively times the odds of abortion for those cows approximately 3.5 years of age (Waldner 2014).

Three year average weaning rates for heifers, second-mated, and mature cows were summarised as between 75-78%, 46-65% and 61-72%, respectively following a survey of the Barkly and Katherine regions of the Northern Territory Cowley *et al.* (2014). However, a research study conducted within the Northern Territory assessing the impact of cow liveweight at weaning and pregnancy reported pregnancy percentages much lower than that captured by survey with 73% of collaborating herds (N=11) achieving pregnancy percentages <25% (Schatz and Hearnden 2008).

From the data published between 1990-2010, descriptive summaries of pregnancy percentages and foetal/calf losses values observed for beef herds across northern Australia are presented in Table 2-1. The characteristic pattern of heifers in northern Australia is for them to fail to conceive as first-lactation cows and conceive again in the subsequent year as 4 year olds (Entwistle 1983).

Table 2-1. Distribution of published reproductive rates by class of management group from 1990 onwards for beef herds located across northern Australia (Hasker 2000; Schatz and Hearnden 2008; Burns *et al.* 2010)

		Percentile		
Animal class	Herds	25^{th}	50^{th} (median)	75^{th}
		Annual pregnancy percentage (%)		
Heifer	16	74	84	87
First-lactation	16	6	17	54
Mature/Mixed	13	78	81	90
		Confirmed pregnancy to weaning loss (%)		
First-lactation	15	12	21	32
Mature/Mixed	12	8	14	20

2.6.3.2 Breed effects

Most beef herds of northern Australia are infused with some *B. indicus* content with herds of high *B. indicus* content generally located in the northern live export region. Breed effects can potentially be considered as a general representation of inter-breed differences in the frequency of desirable or undesirable traits associated with the measure of reproductive performance. The reproductive performance of heifers and cows of various *B. indicus* content has been compared to other breeds. The fertility of Brahman cattle is generally considered to be less than that of *Bos taurus* breeds (Schatz *et al.* 2010). However, under the harsh tropical climatic and environmental conditions they are likely to perform better than other breeds (Perkins *et al.* 1988).

The interval from post-partum to first ovulation and first oestrus tend to be longer in *B. indicus*, and particularly in first-lactation cows (Teleni *et al.* 1988). A large study assessing lifetime reproductive performance of Brahman and Tropical Composite genotypes has recently been conducted under tropical conditions in Queensland, with Brahman cows having longer days to calving (+20.2 days) and lower calving and weaning rates (-9 percentage points and -10 percentage points, respectively) (Johnston *et al.* 2013). Longer lactation anoestrus interval (+56 days) and lower lactation cycling rates (-22 percentage points) were also reported for first-lactation Brahman cows.

Breed effects on calf survival have been reported previously (Reynolds *et al.* 1980; Holroyd 1987; Prayaga 2004; Casas *et al.* 2011; Bunter *et al.* 2013). The mechanism that breed affects calf survival is suggested to relate to factors associated with maternal instincts, risk of dystocia and calf viability (Bunter *et al.* 2013). Bunter *et al.* (2013) reported lower survival rates for Brahman calves compared to tropical composite calves, which appeared to be described by calf birthweight, cow teat and udder scores. The prevalence of bottle teats was greater in Brahmans than that of tropical composites, which has been identified as a major causal factor of mortalities (Holroyd 1987). In contrast, other studies have reported the prevalence of bottle teats for Brahmans to be less than those observed for other breeds where bottle teats was identified as the cause of postnatal loss for ≥75% Sahiwal cows in 21% of cases compared to 2% of cases for ≥75% Brahman cows (Holroyd 1987). Lower calf birthweights are a characteristic of *B indicus* genotypes and even though this has benefits in reducing the risk of dystocia (Johanson and Berger 2003) it has also been associated with increased mortality (Prayaga 2004; Bunter *et al.* 2013).

2.6.3.3 Lactation

The association between lactation status and reproductive performance has been well established and extensively reported from observational studies of cows in commercial and research herds. Suckling has been identified as a major determinant of the interval between calving to first ovulation (Short *et al.* 1990) and moderates the associated effects of class of animal (Short *et al.* 1990), BCS at calving and postpartum dietary intake (Richards *et al.* 1989). The effect of suckling influences hormonal regulation of follicular development and ovulation, resulting in postpartum anoestrus, and the effect is heightened for first-lactation cows and at low BCS. This, prolongs the efficiency with which cows achieve pregnancy, which ultimately results in cows calving later in the season and at increased risk of failing to conceive prior to end of mating. Lactation anoestrus is under genetic control and lactation cyclicity rates are observed as being much lower in first-lactation Brahman cows (71%) compared to those of Tropical composites (93%). Managing the duration of lactation through timing of weaning (and mating) has resulted in significant improvements in reproductive performance (Sullivan and O'Rourke 1997).

The associated effects of lactation are confounded by breed (Baker 1969; Johnston *et al.* 2013), BCS at calving (Montiel and Ahuja 2005), time of calving and the associated effects of postpartum nutrition and energy balance. Any studies assessing the impact of lactation need to partition the effects of other confounding factors to allow an independent assessment of lactation. After partitioning the effects of liveweight, Age and breed, Mackinnon *et al.* (1989) reported large and negative lactation effects on calving rate in the current year. However, repeated lactation success had a positive effect on calving rate and was potentially a useful indicator of heightened fertility.

Observed pregnancy percentages of lactating cows are generally reported to be in the order of 20-75 percentage points lower than those observed for non-lactating cows in tropical regions of Queensland and Northern Territory (Perkins *et al.* 1988; Burns *et al.* 2010). However, much lower differences, approximately <20%, have been reported for herds in more productive areas (Holroyd *et al.* 1988). In addition, Bunter *et al.* (2013) reported an association between cows successfully rearing a calf in the previous year (ie. lactated) and reduced prevalence of calf mortality, however they determined this to stronger predictor in cows 4-7 years old.

2.6.3.4 Month of Calving

The associated effects of time of calving on reproductive performance and production are well established and recognised (O'Rourke 1994). Time of calving effects are likely to be indirectly associated with reproductive performance through BCS at calving, pre- and post-partum nutrition and energy balance (Section 2.6.2.1), duration of lactation, and cycling during the mating period. In addition, time of calving is likely to also be associated with calf loss due its correlation with environmental (such as heat stress; Section 2.6.1.3) and managerial factors (such as mustering; Section 2.6.4.1).

In northern Australia, rainfall is strongly influenced by the presence of monsoons and thus, the majority of annual rainfall occurs during summer between November and April (Nicholls *et al.* 1982). This varies across northern Australia with winter rains increasing in a southerly direction and along the eastern coast (Nicholls 1984). The preferred time of calving generally corresponds to improving pasture quality and quantity to support the additional nutritional requirements of lactation to minimise liveweight and BCS loss. Therefore, the preferred times of calving suggested for Southern Queensland is between August to September increasing to November to December in northern Northern Territory, and December and January in north Queensland (Dodt 2000). However, external factors such as market drivers and availability of labour at critical time points also influence this.

In the Top End region of the Northern Territory cows that calved in September, and likely to correspond to first rains of the season, were estimated as having conception rates 7, 10 and 27 units higher than those calving during October, November and after December, respectively (O'Rourke 1994). However, these effects were confounded by a December to May mating period and lactation anoestrus. In the same study, for those cows that contributed a weaner in June, cows that calved between January and March had pregnancy percentages 13 percentage points higher than those calving during November to December and corresponded with shorter period of lactation and lower weaner weights. However, the author cautioned that cows calving during May to October, can result in high cow mortality and poor calf growth due to poor pasture availability and quality and unable to support the additional nutritional requirements associated with lactation.

Consistently, under drought conditions cows predicted to calve early in the calving season (between September and November) and of low body condition had the lowest probability of survival (Fordyce *et al.* 1990). In all instances where lactating cows died, calf mortality also occurred. In addition, under normal seasonal conditions observed pregnancy percentages for cows that calved between September and November (79%) were higher than those of cows calving between December to February (50%) and March to May (12%). In the gulf district of the Northern Territory, Schlink *et al.* (1994b) reported that the percentage of cows achieving an inter-calving interval of 12 months was greatest for those cows calving during December/January.

Under research conditions and therefore, potentially at heightened levels of management resulting in an over-estimate of performance commonly observed within commercial enterprises, Cobiac (2006) reported mean inter-calving intervals by month of calving (Figure 2-9). Despite the known limitations of intercalving interval as a measure of reproductive performance (Morton 2010), the lowest mean inter-calving intervals were experienced for those mixed-age cows calving between November to February (12 months), whilst the highest mean inter-calving interval was for those cows calving during May (16 months).

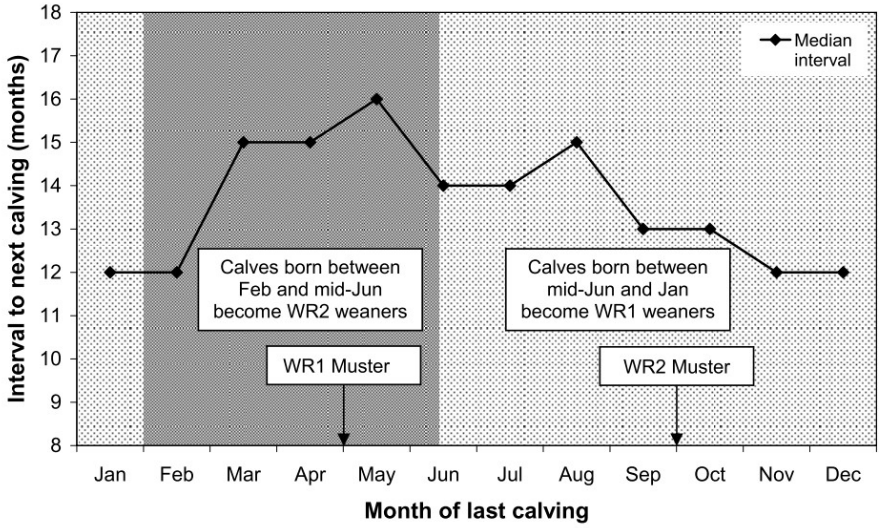

Figure 2-9. Median inter-calving interval for mixed cows between 1997-2001 at Victoria River Research Station, Northern Territory (Cobiac 2006).

Heatwaves are commonly experienced in northern Australia, with summer temperatures generalised as ranging between 25-40^{o}C, with maximum temperatures up to 50^{o}C. In the Barkly Tablelands, Northern Territory, heat stress has been reported as a causal factor of calf loss with 2.6% of observed calf mortalities ascribed to heat stroke (Brown *et al.* 2003). However, the prevalence of calf loss by month of birth was not assessed in this study. Schatz and Hearnden (2008) failed to detect statistical significant differences in the prevalence of foetal/calf loss between month of calving for heifers predicted to calve between October and February in the Barkly Tableland, Northern Territory. No detailed studies relating to northern Australia quantifying the impact of month of calving on foetal/calf loss were identified from the literature. Furthermore, to quantify the effects of month of calving on foetal/calf loss, partitioning of confounding effects such as parity, BCS at calving and nutritional factors is required to allow an independent assessment of the effects associated with month of calving.

2.6.3.5 Hip Height

There are market incentives for north Australian beef producers supplying live export markets to supply large framed cattle of high grade *B indicus* content, which has resulted in the historic selection for Brahman cattle of increased size and height. However, recent reports have suggested these breeding strategies have resulted in reduced profitability and cow herd efficiency due to a reduction of fertility traits such as age at puberty and time to the resumption of cycling in lactating cows (McCosker *et al.* 2010b).

The negative effects of hip height or frame size on reproductive performance have been investigated within a number of research studies (Swanepoel 1994; Vargas *et al.* 1999; Taylor *et al.* 2008; Johnston *et al.* 2009). The biological mechanism for which associated negative effects of frame size or hip height affect reproduction are suggested to relate to the increased maintenance energy requirements of cows of larger mature size and its association with body condition and nutritional status during late pregnancy and early lactation. Due to the confounding effects of breed and body condition score statistical procedures that allow the effects of hip height to be assessed independently should be used, which few studies have done.

Using statistical models that accounted for differences in BCS, Vargas *et al.* (1999) reported statistically significant differences in fertility of young lactating Brahman females that differed in frame size. BCS was not found to modify the effect of frame size on calving rates in second-lactation cows, with cows of large frame size observed to achieve calving rates 21 percentage points less than those of cow lines of small to moderate frame size. However, an interaction between BCS and frame score was found to be statistically significant in ≥3 parity cows with lower calving rates only observed for large frame cows at BCS 5 and 6. It should be noted however, that a potential limitation of this study is that the classification of the foundation herd using hip height to establish mating groups may have been inherently cofounded by historical reproductive performance and the small frame size mating group may have represented cows that have achieved above average early lifetime reproductive performance as early and regular reproduction can restrict mature size (Swanepoel 1994).

A limited number of studies have identified associations of frame size or hip height and calf survival rates. However, Vargas *et al.* (1999) reported a statistically significant reduction (32.8 percentage units) in calf survival rates for large frame score first-lactation cows relative to small to moderate frame scored first lactation cows. However, this association was not apparent in second- and third-lactation cows in the same study.

2.6.4 Managerial effects

2.6.4.1 Mustering around the time of calving

When cows and calves are being moved from pastures into yards, or in pasture rotation movements, cows that get excited or have too much pressure applied, can lose their calves (Grandin 2015). Few studies have assessed the effects of mustering on calf losses. Mismothering resulting in calf mortality has been directly associated with handling of young calves (Rankine and Donaldson 1968) and estimated to result in 4% calf loss due to mustering (Donaldson 1962).

An observational study on calf loss conducted on the Barkly tablelands in the Northern Territory identified mismothering as a significant cause of calf loss (Brown *et al.* 2003). However, calf losses due to mismothering are suggested to reduce with parity (Bunter *et al.* 2013), suggesting the incidence of mismothering would be highest in first-lactation cows. In heifers, maternal instincts are likely to be variable and due to lack of experience in successfully raising calves the incidence of mismothering is likely to be higher for first-lactation cows than those of older cows.

2.7 Summary of epidemiological procedures

Epidemiology is the study of patterns and causes of disease in populations and by increasing our understanding of these patterns and causes informs management practices to reduce the risk of contracting the disease (Sergeant and Perkins 2015). Ultimately, epidemiological research aims to make causal inferences about associations between risk factors and outcomes of interest in a population with a 'cause' inferred as a factor that produces a change in the severity of frequency of an outcome (Dohoo *et al.* 2009). Therefore, it is not uncommon for epidemiological principles to be applied to animal production systems and outcomes of reproductive performance treated as a type of disease; examples of this include Dohoo *et al.* (2001); Waldner and García Guerra (2013); Waldner (2014).

2.7.1 Types of epidemiological study

All epidemiological studies can be classified as either observational or experimental studies. Experimental studies can be generalised as laboratory-based or field-based trials that that control the allocation of study subjects to groups (ie exposed and not-exposed) whilst for observational studies the investigator has no control over the allocation of study subjects to groups and changes in the characteristics of the population are studied without intervention from the investigator (Sergeant and Perkins 2015).

As an observational study is which this research is relevant, further detail on experimental studies will not be provided in this review. In addition, observational studies can be further classified into four broad types: Descriptive, Cross-sectional, Cohort and Case-control.

Descriptive studies have the objective of describing the prevalence of explanatory and outcome variables of interest however, do not employ statistical analytical methods to test associations.

Cross-sectional studies involve the selection of a representative sample of study subjects from the target population and prevalence of the outcome of interest is measured and comparisons among subjects being either exposed or not exposed to risk factors performed. In cross-sectional studies, the numbers of animals either positive or negative for the outcome of interest are not known, nor exposure or not exposed to potential risk factors of interest. Therefore, these studies generally generate prevalence estimates of exposure to risk factors and outcomes of interest, and are particularly relevant to the research this documented relates.

Cohort studies involve the selection of a group of animals exposed to the hypothesised risk factor and a group not exposed to the risk factor and observed to record the development of the disease or outcome of interest in each group. Cohort studies can result in a complete description of the development of disease.

In case-control studies the subjects are allocated to groups on the basis of disease status (ie diseased, not diseased) and compared with respect to presence of hypothesized risk factors. Case control studies are well suited to rare diseases and many potential risk factors can be compared at one time. Case-control studies can be conducted on recent or existing cases of the outcome of interest. A limitation of case-control studies is that they rely on retrospective exposure information and are subject to biases (Dohoo *et al.* 2009).

2.7.2 Source and target population and problems with validity of estimates

The source (or experimental) population is the specific population from which the actual subjects whose data is actually used for analysis (study group) is drawn from whilst, the target population is the population that the study aims to draw conclusions about (Woodward 2005). Observational studies are prone to two main types of errors: random and systematic. Even if derived from a true random sample of a population, estimates derived from a study population will inevitably vary from that of the true values of a target population due to random error, which is inbuilt in the sampling process and exists even if it is a true random sample. However, the impact of random error can be reduced through increases in the sample size and increasing the precision of estimates.

The term validity relates to the absence of systematic bias in that a valid measure of association derived from the study population will have the same value as the true but unknown measure existing in the target population (Dohoo *et al.* 2009). Systematic error results in derived estimates that do not equal those of the target population, and characteristically are not reduced by increases in sample size (Dohoo 2014). There are three main threats to the interval validity of observational studies: selection bias, information bias and confounding bias.

Selection bias is where the animals selected for the study have systematically different characteristics to those not selected in the study. Selection bias occurs either before the study begins (selective entry bias) or during the study (selective survival bias) and can result from the use of herd management characteristics for selection and alters participation or participant behaviour in the study. Cows retained in breeding herds are considered a biased subset of breeding herds in general in that they are likely to be of higher fertility to those of the broader population of cows as generally breeding females must maintain a certain level of performance to maintain their place in the herd. An example of selective survival could be the removal of all non-lactating females at a muster conducted prior to pregnancy diagnosis when pregnancy is the outcome of interest as lactation is highly correlated with pregnancy. In the human epidemiology field this phenomenon is known as the “healthy worker effect”. When selection bias is an issue, the study group should be drawn from animals that had entered the herd during a time period and not those that are in the herd at the commencement of the study.

Other sources of selection bias include: non-response bias and missing data (Dohoo *et al.* 2009). Non-response can result in a bias if the association between exposure and outcome is different within the respondents to those that did not respond. Missing data can also result in a bias if it is not distributed randomly. Missing data requires the investigator to either impute missing values or drop the variable (confounding bias) or response (non-response bias). Loss to follow up bias is similar to non-response bias and exists if there is a differential loss to follow up that is related to the exposure status and the outcome (Dohoo *et al.* 2009).

Information bias arises when the researcher has the wrong information about either an explanatory or outcome variable. There are many causes of information bias including recall bias, imperfect diagnostic tests, and error in data collection or management (Dohoo 2014). Information bias relates to both measurement error (incorrect measurement of continuous variables) and misclassification bias (incorrect classification of categorical variables). Two types of misclassification can occur: non-differential and differential. Differential misclassification relates to when the magnitude or direction of misclassification is different between the two groups (exposed/not exposed) being compared and therefore, can either result in either an increase or decrease in the measure of association. Non-differential misclassification relates to when the misclassification is similar in magnitude and direction between the two groups (exposed/not exposed) and results in a shift in the measure of association towards one if the measure of association is relative (Thrusfield 2005).

Confounding occurs when the effects of two associated exposures or risk factors are not separated and when present, results in the estimated association differing from that of the true effect as the observed measures of association includes the effects of one or more extraneous factors (Dohoo *et al.* 2009). Confounding can result in either a positive or negative shift in the estimates of association and approaches for its control include analytical control, matching and exclusion (Dohoo *et al.* 2009).

2.7.3 Identifying the major determinants of reproductive performance in populations

Although the reproductive performance of beef cows is determined for a cow-year, cow-year events cannot be considered independently as data from populations generally have a natural hierarchical structure and therefore are more likely to share characteristics at different levels of organisation (Dohoo *et al.* 2009). Epidemiologic data can either be clustered over time or in space (Dohoo *et al.* 2001) and if ignored statistical inference can be faulty (McDermott *et al.* 1994; Mason 2001). For beef herds, clustering potentially exists for reproductive production cycles within cows, which in turn are clustered within management groups, which in turn are clustered within herd or property.

Multilevel or hierarchical models are commonly used for the analysis of clustered data. Multilevel models allow the investigator to take the clustered data structure into account to evaluate the effects of independent variables. Some recently published examples where multilevel models have been used in this manner include: risk factors for abortion in cow-calf herds (Waldner 2014); factors and indicators for clinical mastitis during lactation in pasture-fed dairy cows (Hammer *et al.* 2012); factors associated with morbidity, mortality, and growth of dairy heifer calves (Windeyer *et al.* 2014) and factors associated with non-pregnancy (Waldner and García Guerra 2013).

Multivariable models have also been used to determine which level of organisation contributes to most of the variance for the outcome of interest. The identification of sources of variation between levels of organisation can be used to direct future research and management activities as directing future resources at levels identified as being the source of most variation will have the greatest impact on the outcome. A recently published example where multilevel models have been used in this manner include Dohoo *et al.* (2001), which determined that >90% of the variation rested at the lactation (cow-year) level and that therefore, management of reproductive performance at the individual lactation level would have the greatest impact on overall performance for the target population.

A measure of importance of factors associated with reproductive performance is population-attributable fraction. Population-attributable fraction provides an indication of the impact that removal of a factor would have on the prevalence of the outcome of interest in the population. Population attributed fractions take into consideration the prevalence of the factor in a population and the difference in the frequency of the outcome of interest between those animals exposed to the factor and others not (Thrusfield 2005; Dohoo *et al.* 2009).

2.8 Aims and objectives of thesis

It is evident from the review of the literature that many factors affect the reproductive performance of beef cows in northern Australia. Historically, many detailed studies have been conducted to explain the impacts of certain risk factors at a single level (ie herd- or reproductive production cycle-level) or have assessed the association of risk factors using univariate approaches. Whilst these studies have considerably improved our understanding and provide detailed information on the possible magnitude of effect for the risk factor of interest, their ability to be generalised to the broader population is limited due to potential biases. In additional, even though studies conducted at the herd-level provide increased understanding of the overall observed associations between risk factors and outcomes of interest, they often do not consider potential differences in the frequency of characteristics of study groups that may result in confounding (Dohoo *et al.* 2009). In addition, many of these studies have been conducted within research facilities or commercial properties involved in specific research projects and therefore, there is a need to validate the findings for the commercial beef cattle population of northern Australia.

There is also a need to estimate the contribution of the herd-level to the total variance in reproductive performance to guide intervention and informing how producers can focus management practices to maximise the probability of heifers and cows achieving pregnancy or minimising their risk of failing to contribute a live calf at muster. Such information is also needed to prioritise future research, development and extension directions and investment.
The specific aims and objectives of this thesis are:

1. To describe the demographics and nutritional, breeding and herd management practices and policies employed by the source population.
2. To describe the variation in reproductive performance of commercial beef herds across northern Australia, and estimate achievable levels.
3. To describe the prevalence of those risk factors determined as major sources of variation of measures of reproductive performance occurring within the source population.
4. To identify the major associations between herd management practices, nutritional, environmental and infectious disease factors and individual cow attributes, and:
    a. the probability of lactating cows being pregnant within four months of calving
    b. the risk of failing to achieve pregnancy in an annual production year
    c. the risk of pregnant females failing to wean their calf

    on commercial beef cattle breeding properties in northern Australia.

Chapter 3 Generic Methodology

3.1 Overview of study design

A cross-sectional observational study was conducted in commercial beef breeding herds located across northern Australia. A multi-stage selection method was implemented with selection of herds, management groups within herds and females within management groups. Seventy-eight commercial beef cattle properties within the major beef breeding regions of Queensland, the Northern Territory and Western Australia participated in the project. Within each herd, a typically managed group of heifers and mature cows were selected and reproductive performance monitored over 3 to 4years.

A total of 126,612 annual production cycles, derived from approximately 78,000 individually identified females managed in up to 165 breeding groups were studied. Associations between three reproductive outcomes and multiple exposure variables (candidate risk factors) were assessed using multivariable multilevel logistic models.

Cooperating herds were progressively enrolled over 2 years. Initially, a pilot study involving 13 properties, each enrolling a management group of typically selected maiden heifers, was undertaken during 2007-2008 to inform the management and design of the larger main study conducted during 2009-2011.

3.2 Organisation structure

A regional co-ordinator was appointed to each of the four geographical regions. For each enrolled property the responsibility for co-ordination and collection of all cattle, nutritional, environmental and herd management data was the project liaison officer, and the regional coordinator and private veterinary practitioner who routinely serviced the property, respectively.

3.3 Feedback to herd managers

General details of study results and summaries of findings specific to individual herds were prepared for herd managers, as results became available during the study. Regional co-ordinators were responsible for delivering these findings to managers of study herds.

3.4 Target population

The target population was annual production cycles commencing for commercial beef herds serviced by accredited cattle veterinarians during the study period. The study aimed to identify findings that could be extrapolated to the external population, commercial north Australian beef herds.

3.5 Sample size estimates

A sample size calculation to determine number of groups and breeding females to be enrolled were performed using WinPepi (version 11.61) assuming a single-level study with reproductive outcomes expressed as a proportion for each herd and treated as a continuous variable having a normal distribution. The outcome measures that were assessed were proportion of lactating cows that were pregnant within 4 months of either exposure to bulls or a significant change in the nutritional status (ie onset of wet season). A standard deviation of 11% was assumed.

The number of herds required to have 80% power (generally accepted level of power for this type of epidemiological study) to detect differences in means ranging between 2.5 percentage points to 10 percentage points as significant at P<0.05 were estimated for 10% and 50% of herds exposed to a factor of interest and are presented as Table 3-1.

Table 3-1: Estimated number of groups required to detect herd-level differences in percent pregnant within 4 months

Percentage of herds exposed to factor of interest[a]	Difference between means to be detected (percentage points)	No. groups required
10%	2.5	1,690
10%	5	424
10%	10	107
50%	2.5	608
50%	5	152
50%	10	38

[a]for example groups using or not using a management practice such as early weaning or a disease control measure such as vaccinating against vibriosis

Using the above findings, enrolment of 154 groups enabled small effects (around 5 percentage point differences) of factors common to these groups to be detected. However power to detect less common (around 10% of groups exposed) groups-level factors will be lower. While this should provide adequate power for common property level exposures such as mating practice there will be only moderate power to detect region–level effects.

The number of cows required to have 80% power to detect a difference between cows either exposed or not exposed to a factor and where the actual proportions of cattle pregnant vary between 52.5% and 90% as significant ($P<0.05$) were estimated using WinPepi (version 11.61), adjusted for clustering assuming an intra-class correlation of 0.1 and an average of 100 females per group (Dohoo *et al.* 2009) and are presented as Table 3-2. Based on the analysis, power to detect cattle-level effects was high.

Table 3-2: Estimated number of cows required with adjustment for clustering to detect differences in the percentage of cows pregnant within 4 months.

Percentage of annual production cycles exposed	Percent pregnant in exposed group[a]	Percent pregnant in not exposed group	Difference between means to be detected (percentage points)	Estimated number of annual production cycles required[b]
10%	50%	52.5%	2.5	379,756
10%	50%	55.0%	5	94,503
10%	50%	60.0%	10	23,217
10%	80%	82.5%	2.5	227,701
10%	80%	85.0%	5	52,756
10%	80%	90.0%	10	10,791
50%	50%	52.5%	2.5	136,795
50%	50%	55.0%	5	34,117
50%	50%	60.0%	10	8,458
50%	80%	82.5%	2.5	83,407
50%	80%	85.0%	5	19,751
50%	80%	90.0%	10	4,338

[a] for example females lactating or dry

[b]Sample size estimates for the number of annual production cycles required was adjusting for clustering using equation n'=n(1+p(m-1) {Dohoo, 2009 #249@@author-year}.

3.6 Selection of herds and management groups

Beef production systems in northern Australia are quite diverse, varying substantially by marketing options, mating systems and environmental conditions. Some of this diversity between herds is associated with geographic location (Figure 3-1). Herds within Southern and Central Queensland are primarily control mated and turnoff is typically ≤2-years of age and commonly to domestic markets. By contrast, herds within north, north-west and western Queensland, the Northern Territory and northern Western Australia are primarily continuously mated or segregated by either lactation status or expected month of calving, and turnoff is primarily to export markets.

Study sites were identified using a convenience sampling approach based on their nomination of existing clients by regional veterinary practitioners or self-enrolment. Study sites were selected to ensure that a range of marketing options, mating systems and environmental conditions were represeneted and a regional coordinator with sufficient access to sufficient number of herds was available to service the site.

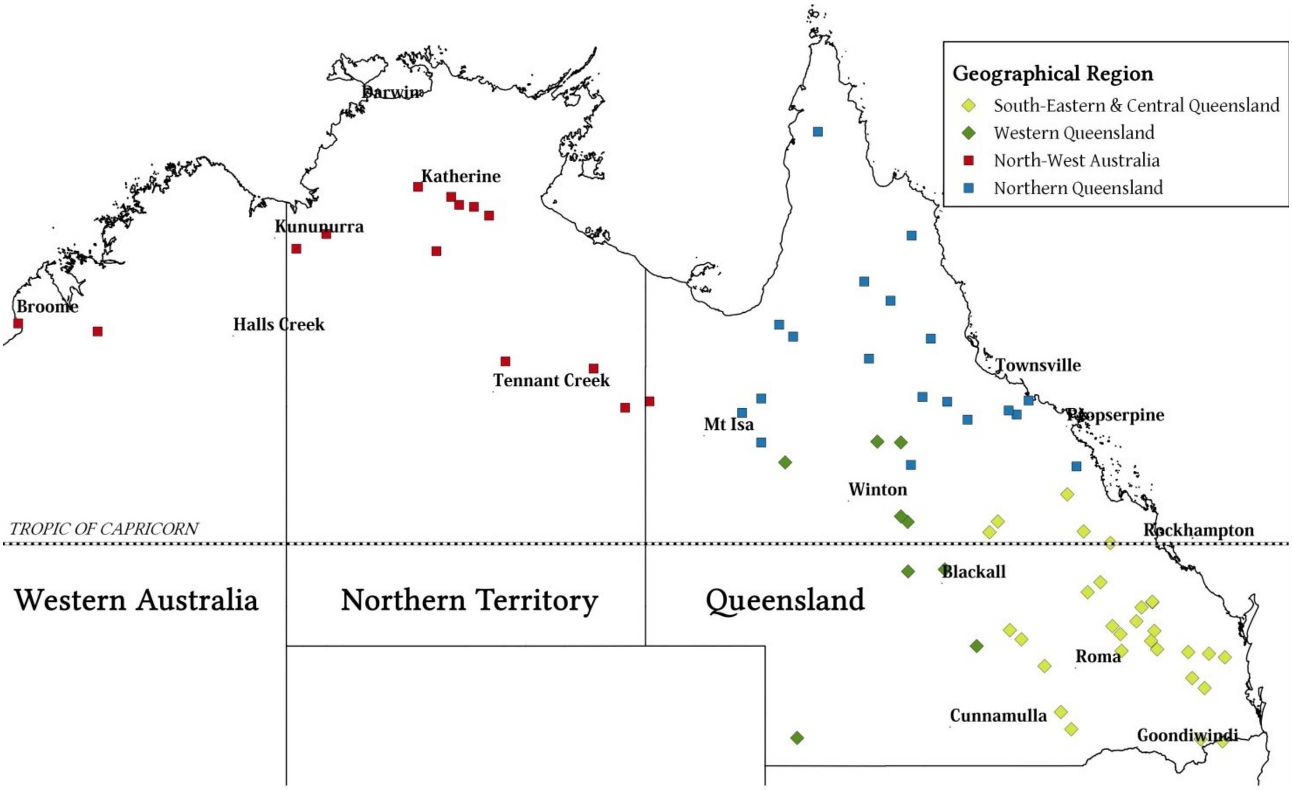

Figure 3-1. Map of enrolled properties by geographical region.

3.6.1 Herd selection criteria

Collaborating properties were selected on the basis of the following criteria:

1) Herd owners/managers were keen to participate and support the study, and were considered likely to maintain accurate records.
2) Properties were considered to be typical for the region with respect to property size and herd management (Table 3-3).
3) Herd owners/managers were prepared to maintain the enrolled management groups on their property, with the exception of females culled as per normal property breeding herd management policy, for the duration of the study.
4) All enrolled females were individually electronically identified for the duration of the study.

5) The herd owner/manager was prepared to attend a one-day training workshop in assessing standing pasture biomass and land condition.
6) Properties had access to satisfactory cattle handling facilities and, herd owners/managers were prepared to ensure that all enrolled management groups were mustered (brought in from their grazing paddock) a minimum of twice a year, once at the time of branding and/or first annual weaning and then again for pregnancy diagnosis either at least six weeks after the bulls were withdrawn or in continuously mated herds at the time of the second (final) annual weaning muster which is usually conducted during the mid-dry season (August-October).
7) All pregnancy diagnosis and foetal aging of enrolled management groups was conducted by accredited cattle veterinarians or accredited beef cattle officers
8) Properties had access to cattle weighing facilities and at a minimum, were prepared to record the individual live weight of all, or a sample of calves weaned each time cows were mustered for weaning.

Table 3-3. Summary demographics and herd management of collaborating properties by country type.

	Southern Forest	Central Forest	Northern Downs	Northern Forest
Property Size (km^2; $1km^2$ = 100 ha)				
N=	16	13	13	23
Median	60	162	364	1,250
Range	12–8,900	49–410	130–16,118	26–4,500
*Paddock size (ha)**				
N=	82	61	80	59
Median	415	714	2,153	2,611
Range	17-4,550	63-2,802	370-71,160	202-16,387
Proportion (%) of properties with different ownership and management structure				
N=	22	12	13	30
Owner/Manager	18 (82%)	6 (50%)	8 (62%)	10 (33%)
Private Manager	1 (5%)	4 (33%)	0 (0%)	6 (20%)
Corporate Manager	3 (14%)	2 (17%)	5 (38%)	12 (40%)
Leasee/Agistee‡	0 (0%)	0 (0%)	0 (0%)	2 (7%)
Breeding herd size (number of cattle)				
No. responses	18	13	13	23
Median	572.5	1,200	2,400	3,700
Range	280-8,056	350-3,000	550-44,000	220-15,097
Proportion (%) of properties with breeding females of different Bos indicus content				
N=	21	13	13	31
<50% Bos indicus	14 (67%)	3 (23%)	1 (8%)	0 (0%)
50 to <75% *Bos indicus*	4 (19%)	8 (62%)	9 (69%)	4 (13%)
≥75% Bos indicus	3 (14%)	2 (15%)	3 (23%)	27 (87%)
Proportion (%) of properties with different typical sizes of management groups(number of cattle)				
N=	21	13	13	31
<150	9 (43%)	4 (31%)	3 (23%)	0 (0%)
150 to <400	11 (52%)	9 (69%)	6 (46%)	22 (71%)
≥400	1 (5%)	0 (0%)	4 (31%)	9 (29%)
Proportion (%) of properties with different mating management				
N=	19	13	13	30
Mated for <3m	8 (42%)	5 (38%)	5 (38%)	1 (3%)
Mated for 4-7m	8 (42%)	8 (62%)	3 (23%)	10 (33%)
Mated for >7m	3 (16%)	0 (0%)	5 (38%)	19 (63%)

3.6.2 Management group selection criteria

The reproductive performance of beef breeding females is generally lowest during their first lactation. Study groups were selected to ensure that herds with a range of cow-age classes were monitored and therefore, wherever possible a group of heifers and a group of cows were initially enrolled from each herd. Cooperating properties and groups were progressively enrolled over 2 years (Table 3-4).

Table 3-4. Number of groups enrolled in each country type by cow-age class/cohort of female.

Country Type	2008 Heifers	2009 Heifers	2010 Heifers	2011 Heifers	2009 Cows
Southern Forest	3	13	1	1	22
Central Forest	3	8	1	0	13
Northern Downs	4	8	2	1	13
Northern Forest	3	14	5	0	27
Total	13	43*	9	2	75**
			142		

* Processed as 47 unique management groups at time of induction

**Processed as 104 management groups at time of induction

On properties which typically managed their breeding females in groups of 100 to 500 females, all females were enrolled in the study. However, on properties where management groups of greater than 500 females were typically managed, a strategic sampling design was sometimes initially used to select a representative sample of 300 females from the management group to subsequently enable all data collection to be completed in a single day. To determine which females were enrolled, the total number of females in the management group was divided by 300 and then every nth (5th, 6th etc) female was selected as they presented at the cattle handling facility (crush, chute) during the first data collection muster.

3.6.3 Regional categorization of herds

After consideration of all published methods of regionalising individual properties and detailed discussions with enrolled beef cattle producers, it was decided that enrolled properties would be allocated to one of four country types according to the production potential of the grazing land utilised during the study (Figure 3-2). Properties were assigned to one of four broad country types following a subjective assessment of the production potential of the grazing land and cross-referencing with pasture and vegetation descriptions reported by the herd owners/managers. Critically, property owner/managers were asked to provide an estimate of the annual growth of yearling steers (AGYS) for the country where the cattle enrolled in the study were grazed. Properties with forested land-types with fertile soils in the central and south-east regions of Queensland were differentiated by being outside (Southern Forest; median AGYS 200kg) and within (Central Forest; median AGYS 180kg) the northern Brigalow Forest. In the northern areas of Queensland, Northern Territory and Western Australia, properties with land types that were predominantly treeless black soils plains (Northern Downs; median AGYS 170kg) were segregated from those with forested land-types and low fertility soils (Northern Forest; median AGYS 100kg).

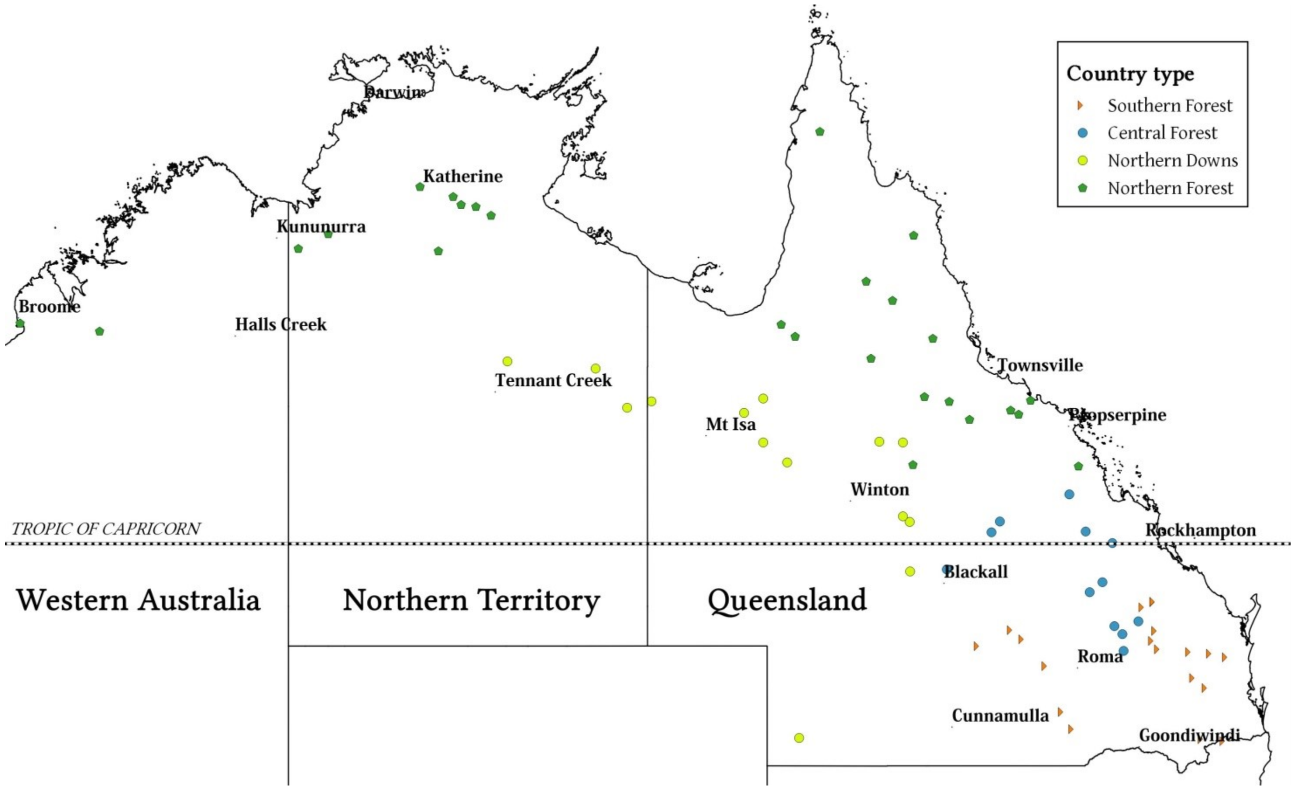

Figure 3-2. Map of enrolled properties by country type.

3.6.4 Summary of flow of selected herds, management groups and animals

In total, 142 groups were enrolled during the study period representing 75 different properties. Six properties withdrew from the project; one in southern Queensland, three in central Queensland, one in northern Queensland and one in the Top End/Kimberley. They withdrew for a variety of reasons associated with their ability to provide and support the required data collection, through to property viability and sale of the property. As a result of the withdrawals, 14 groups were lost to follow-up (Table 3-5). Similarly, the capture of individual animal data from musters was missed at various stages throughout the study (Table 3-6). The main reason for missing the data capture events was due to animals failing to be mustered for various reasons including: the uncontrolled movement of cattle between paddocks; cooperating herd manager's combining the branding/weaning muster with the pregnancy testing muster and therefore only conducting one annual muster; and on a limited number of occasions herd managers notifying of a muster with insufficient lead time to allow data recorders to travel to the study site to capture the required data. For reasons such as: study site withdrawals, complete loss of individual identification, unreported culling or repeated failure to muster a number of animals were lost to follow-up.

Table 3-5: Flow of selected groups through the study

Year and cow-age class at induction	Muster	Processed	Not Mustered	Lost to follow up
2008 Heifers	2007 Pre-join§	6	7	0
	2008 Preg. Diag.	13	0	0
	2009 Branding/weaning	11	2	0
	2009 Preg. Diag.	11	2	0
	2010 Branding/weaning	11	1	1
	2010 Preg. Diag.	11	0	1
	2011 Branding/weaning	10	1	0
	2011 Preg. Diag.	11	0	0
2009 Heifers	2009 Preg. Diag.	43	0	0
	2010 Branding/weaning	37	3	3
	2010 Preg. Diag.	38	1	1
	2011 Branding/weaning	35	4	0
	2011 Preg. Diag.	35	4	0
2010 Heifers	2010 Preg. Diag.	9	0	0
	2011 Branding/weaning	7	0	2
	2011 Preg. Diag.	7	0	0
2011 Heifers	2011 Preg. Diag.	2	0	0
Cow	2009 Branding/weaning	64	11	0
	2009 Preg. Diag.	72	2	1
	2010 Branding/weaning	64	8	2
	2010 Preg. Diag.	68	1	3
	2011 Branding/weaning	59	12	0
	2011 Preg. Diag.	67	2	0

§ A muster of heifers conducted prior to mating was optional.

Table 3-6: Flow of animals through the study

Year and cow-age class at induction	Muster	Mustered and Kept	Mustered and Culled	Not Mustered	Lost to follow up
2008 Heifers	2008 Preg. Diag.	5379	238		
	2009 Brand./Wean.	3614	172	1234	359
	2009 Preg. Diag.	1757	379	719	1993
	2010 Brand./Wean.	1784	134	320	238
	2010 Preg. Diag.	1299	260	475	70
	2011 Brand./Wean.	785	87	902	0
	2011 Preg. Diag.	1306	80	301	0
2009 Heifers	2009 Preg. Diag.	8584	1510		
	2010 Brand./Wean.	5117	458	1595	1414
	2010 Preg. Diag.	5032	730	261	689
	2011 Brand./Wean.	3596	121	1576	0
	2011 Preg. Diag.	3464	249	1187	272
2010 Heifers	2010 Preg. Diag.	1425	195		
	2011 Brand./Wean.	801	59	386	179
	2011 Preg. Diag.	891	54	242	0
2011 Heifers	2011 Preg. Diag.	63	5		
Cow	2009 Brand./Wean.	21516	167		
	2009 Preg. Diag.	27855	2588	670	365
	2010 Brand./Wean.	23020	1515	5456	2596
	2010 Preg. Diag.	24121	4604	1459	2033
	2011 Brand./Wean.	15311	895	9390	0
	2011 Preg. Diag.	16930	1493	5890	0

3.7 Data collection and management

The timing of measurements and events throughout the study are presented below as Figure 3-3.

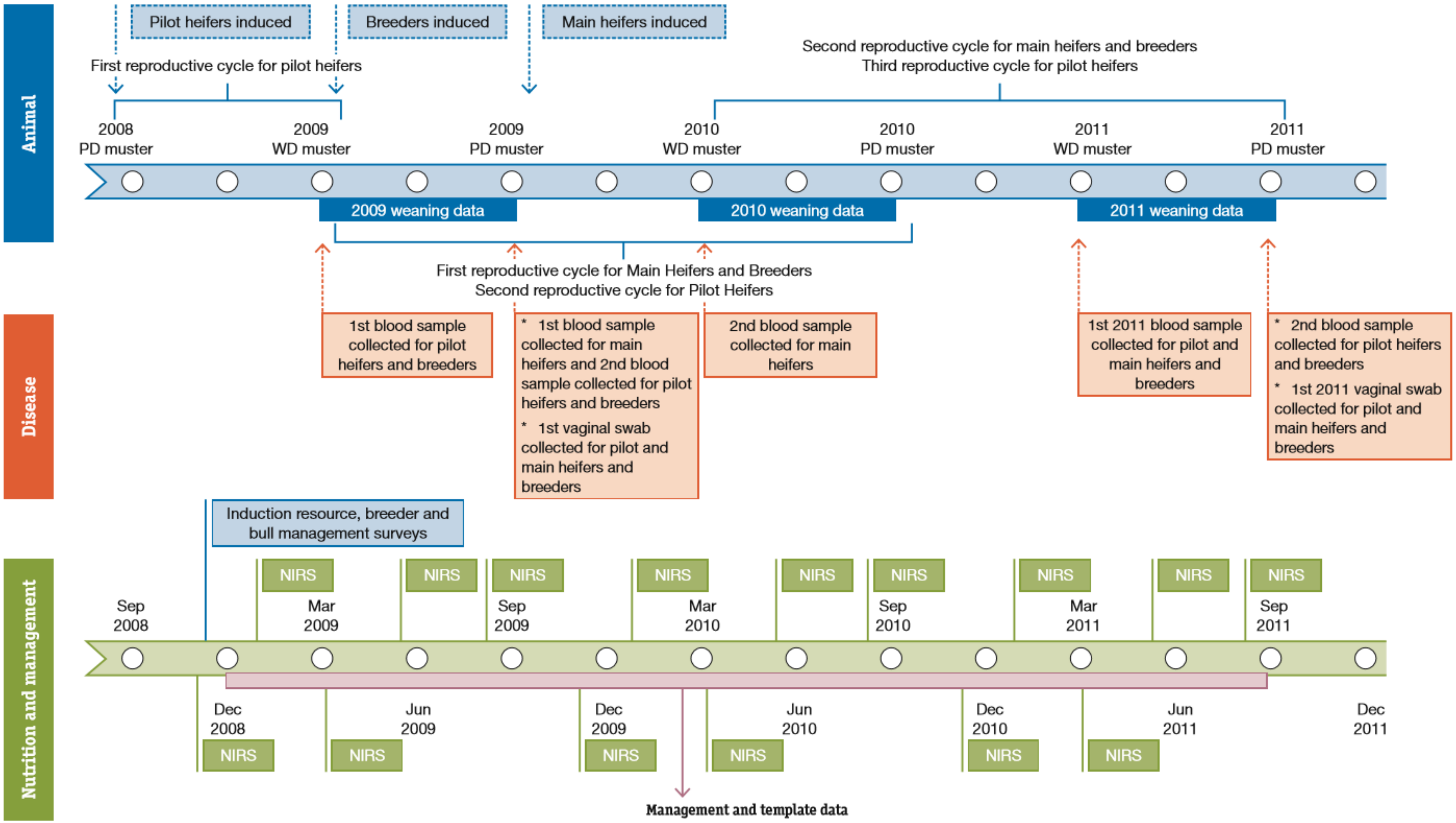

Figure 3-3. The timing of measurements and events (NIRS: Near infrared spectroscopy, WD muster: Branding/Weaning muster, PD muster: Pregnancy diagnosis muster).

3.7.1 Property environmental and herd management factors

At the commencement of the study, property- and herd-level management data were collected using three survey templates that were completed by the cooperating herd owner/manager usually in consultation with the regional co-ordinator (Figure 3-3). Areas covered within the survey templates included property resources and infrastructure, annual pasture management, breeding female management, mating management and feral pest and infectious disease control strategies. Using the GPS location of a paddock or homestead daily interpolated environmental data (such as temperature and rainfall) were obtained from the Australian Bureau of Meteorology (BOM).

3.7.2 Animal factors

All animal data was captured electronically using a commercial data collection system (AgInfoLink BeefLink™) that utilised individual animal identification devices. Outcross Performance Pty. Ltd. a commercial beef cattle data capture company was contracted to provide the cattle data capture programme and to conduct all electronic crush-side data collection in Queensland, however for the Northern Territory, Kimberley and Pilbara properties, the majority of data collection was performed by the NTDPI&F research staff using the same equipment and software.

All enrolled heifers and cows were individually identified using National Livestock Identification System (NLIS, www.nlis.mla.com.au) compliant radio frequency identification device (RFID) ear tags. RFID tags were replaced if the tag was missing or was present but could not be read. In the event of a RFID tag being replaced, data linkages to previous performance records were often able to be established as most study animals were also individually identifiable by a visual identification tag. The estimated annual incidence of tags being replaced during the course of the study was 2.6% (95% CI, 1.5-3.7%) per annum. However, the percentage of tags being replaced per annum appeared to increasing over time with 1.5% of tags being replaced by 18 months, 2.7% being replaced in the subsequent 12 months and a further 4.1% being replaced in the following year (Figure 3-4).

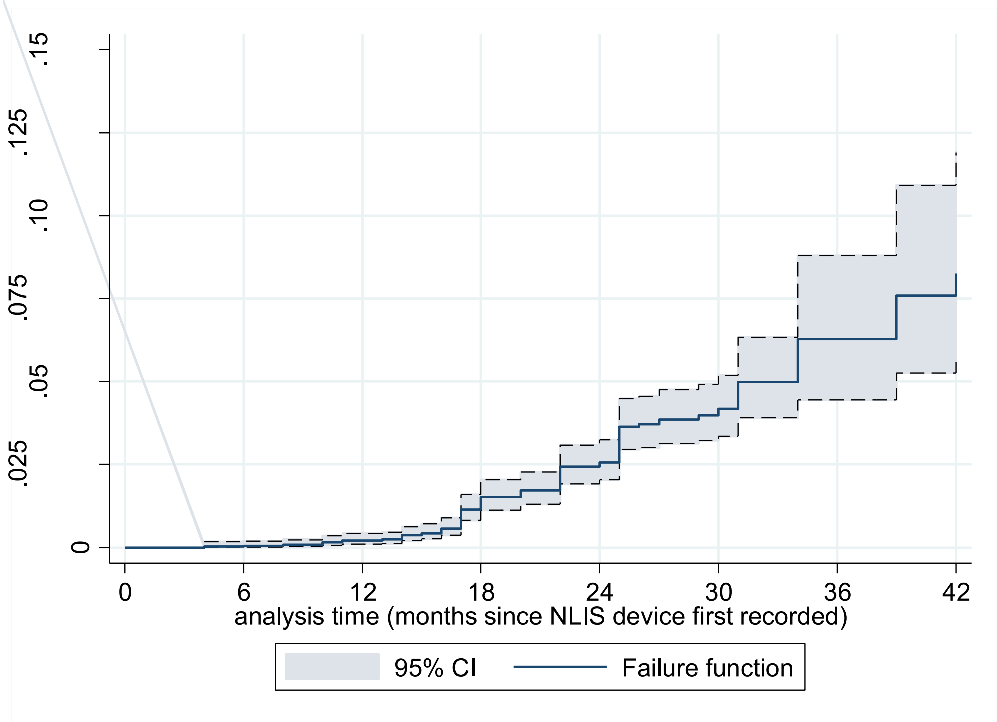

Figure 3-4: Kaplan-Meier estimate of the probability of NLIS ear tags being replaced over the course of the study, with 95% confidence intervals (CI).

Performance and explanatory data were recorded twice a year for each heifer or cow at the main branding or weaning muster and again at the pregnancy diagnosis (PD) muster (Figure 3-3). The average interval between musters was 3.8 (95% CI, 3.6-4.0) months. At a study animal's first muster information on breed type and year brand were also captured. At each muster, body condition score (BCS 1 = very thin to BCS 5 = very fat scale), lactation status (determined by visual assessment of the udder or attempted expression of milk) and udder score (normal or abnormal i.e likely to affect calf survival) were assessed and recorded. At the pregnancy diagnosis muster foetal age was recorded for all pregnant females. Wherever possible the liveweight of cattle was determined at each muster. Liveweight data was captured for 77.5% of management groups at the branding or weaning muster and 77.8% of management groups at the pregnancy diagnosis (PD). The management of cattle prior to weighing (duration between entry into the cattle yards and weighing and duration without feed and/or water) was recorded. The animal's status within the herd was recorded as either Kept or Culled at each muster. Details of the paddock the cattle were mustered from and returned to were recorded at each muster, as well as a unique management group identifier (group id).

Hip height was captured once for cows, at their first pregnancy diagnosis muster, and twice for heifers, at their first pregnancy diagnosis muster and at the pregnancy diagnoses muster the following year. Hip height measurements were determined according to Fordyce et al (2013).

A total of 126,612 annual production cycles were described in the study. The inclusion of individual animal data into the analysis dataset was determined by animals providing information on either rearing a calf or reconception for at least one reproductive cycle. Therefore, heifers that were culled at pregnancy diagnosis (induction) were excluded from the dataset and cows that were either culled at their first branding/weaning muster or pregnancy diagnosis muster were also excluded from the analysis dataset. Animals that were culled at their first muster have not been included in this analysis file as they lack explanatory data that can be used to investigate risk factors and maiden heifers becoming pregnant. A total of 12,458 annual production cycles were excluded from analysis for various reasons that are presented below as Table 3-7. The number of annual production cycles described and retained in the analysis file by year and age class at induction is presented as Table 3-8.

Table 3-7: Number of annual production cycles described during the study period and subsequently excluded, by reason for exclusion.

Reason	Age class at induction		TOTAL
	Cow	Heifer	
Recorded prior to mating	0	56	56
Lactating heifer at induction	0	43	43
Cow recorded during pilot	328	0	328
Failed to contribute outcome[#]	3,599	53	3,652
First mustered during 2011	5,348	0	5,348
No individual ID	685	6	691
Property withdrew from project	1,525	815	2,340
TOTAL	11,485	973	12,458

Table 3-8: Number of annual production cycles described and retained in the analysis file for each year of observation.

Year and cow-age class at induction	Year of observation				Total
	2008	2009	2010	2011	
Cows		29,833	32,260	20,838	82,931
2008 Heifers	3,262	2,788	2,170	1,574	9,794
2009 Heifers		8,212	6,588	4,307	19,107
2010 Heifers			1,296	1,026	2,322
Total	3,262	40,833	42,314	27,745	114,154

3.7.3 Nutritional management factors

To facilitate the capture of the data required to define the nutritional status of each enrolled breeding group and to ensure its consistency and validity, property owners/managers were required to attend a one day Stocktake (futurebeef.com.au) workshop to develop the necessary skills for measuring and reporting nutritional and environmental parameters. Twelve workshops across northern Australia were held at the beginning of the study.

3.7.3.1 Diet quality

A representative sample (based on approximately 10-15 animals) of fresh faeces was collected from each enrolled management group in January, March, May, August and November. Faecal samples were generally collected at places where cattle congregated such as watering points, supplement stations and cattle 'camps'. On a few occasions, these sampling months coincided with either a pregnancy diagnosis or branding/weaning muster and dung samples were collected per rectum. For those management groups being supplemented at the time of collection, supplements were not withdrawn prior to sampling. If, for logistical or other reasons, a sample was not collected in the scheduled collection month every effort was made to ensure a sample was collected in the month following.

Following collection, samples were usually stored frozen and were either sun or oven dried prior to being dispatched for faecal near infrared spectroscopy (F.NIRS) analysis. A survey template was completed at the time of each faecal collection and included the following; date of collection, management group identification code, location of cattle within the property (paddock), supplements being fed (Section 3.7.3.2), estimated quantity of pasture available (Section 3.7.3.3), and estimated frequency distribution of body condition scores by lactation status.

Using F.NIRS dry matter digestibility (DMD) and crude protein content (CP) were determined, and faecal phosphorus (P) content was estimated using wet chemistry techniques (Zarcinas *et al.* 1987; Coates 2004). The study population represented the full spectrum of soil P statuses based on McCosker and Winks (1994). However, large proportions of herds within the Northern Forest were grazing areas classified as 'deficient to acutely deficient'.

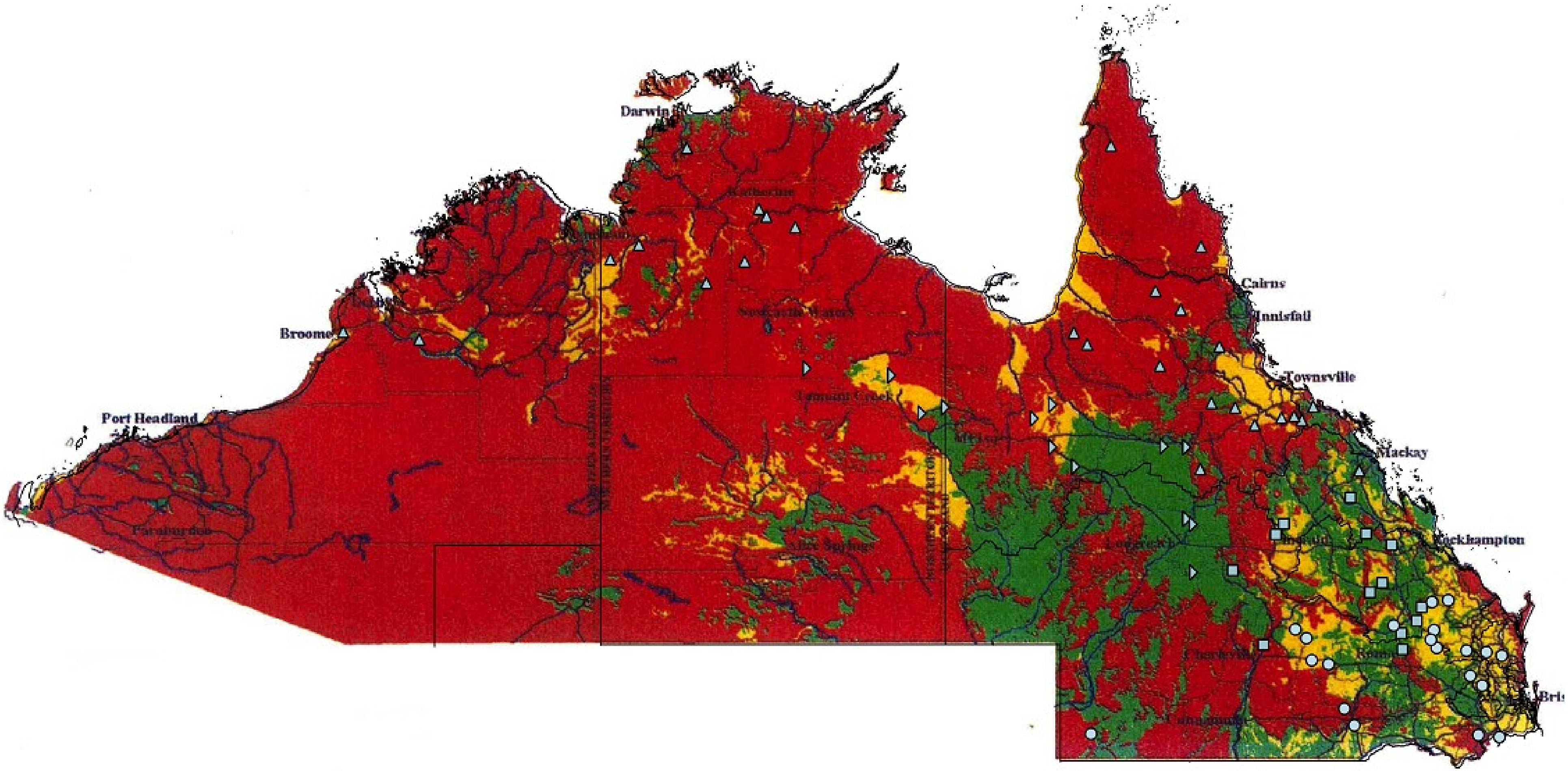

Figure 3-5: Map showing the general extent of phosphorus deficiency (■ Deficient to acutely deficient; ■ Marginal deficiency or mixed; ■ Adequate or unknown) over northern Australia (McCosker and Winks 1994) with collaborating study herds and country-type (○ Southern Forest; ☐ Central Forest; ▷ Northern Downs; Δ Northern Forest) identified.

3.7.3.2 Provision of supplements

Co-operators were asked to keep records of any supplements fed. Amount and dates fed, type, and composition of supplement were recorded both on the faecal collection and on a supplementation template.

3.7.3.3 Available standing biomass of pasture

Owners/managers were asked to estimate the average standing biomass of pasture for the grazed area (within 3-5 km from water) of the paddock/s the management group had access to according to the following six categories: <500 kg/ha, 500-<1000 kg/ha, 1000-<2000 kg/ha, 2000-<3000 kg/ha, 3000-<4000 kg/ha and ≥4000 kg/ha. Cooperating producers were provided with photo standards for each category and for the major pasture communities relevant to their property.

3.7.3.4 Paddock area and distances to water points

Data from 314 paddocks grazed by study groups were digitised from either paper based maps, satellite maps, existing digital maps, or GPS point. However, data from 96 paddocks were not included in the analysis dataset due to insufficient information or issues relating to data integrity. Where short duration grazing using a series of small paddocks (e.g cell grazing) was practised those paddocks were classified as one paddock. Where paddocks were subdivided but the gates between sections were left open, or where adjacent paddocks were judged to be insecure (poor fences), these were also classified as one paddock.

Paddock areas were calculated using the ArcMap GIS program. To determine the potential utilisation of pasture in each paddock grazed permanent water points were added to the digitised maps. AgData's Phoenix mapping software was used to estimate areas of each paddock within 1.5, 2.5, and >2.5 km from permanent water points.

3.7.3.5 Stocking rates and cattle movements

An annual cattle movement and stocking template was completed by owners/manager and contained information relating to the movement of management groups of cattle throughout the year by paddock. Using calculated paddock areas, it was anticipated that this information could be used to derive estimates of stocking rates. However, this was found to be generally not possible because not all cattle on a property were enrolled in the study, and the regular deliberate inter-management group movement of cattle thought out the year.

3.7.4 Data management

Data were managed using four main databases established in Microsoft® Access. Data management and flow is summarised in Figure 3-6.

As an additional check that all required cattle data had been received, a Data Collection Log was kept. This file incorporated such information as the start and end dates for each lot of property data collected, the property code and management group ID, whether it was a pregnancy diagnosis or branding/weaning muster, the number of cattle processed, the name of the data collector, whether a summary report of cattle performance had been generated and forwarded to the owner/manager, and any notes on the data collection. The Data Collection Log was forwarded to the Cash Cow Project Manager along with the 'cleaned' data file.

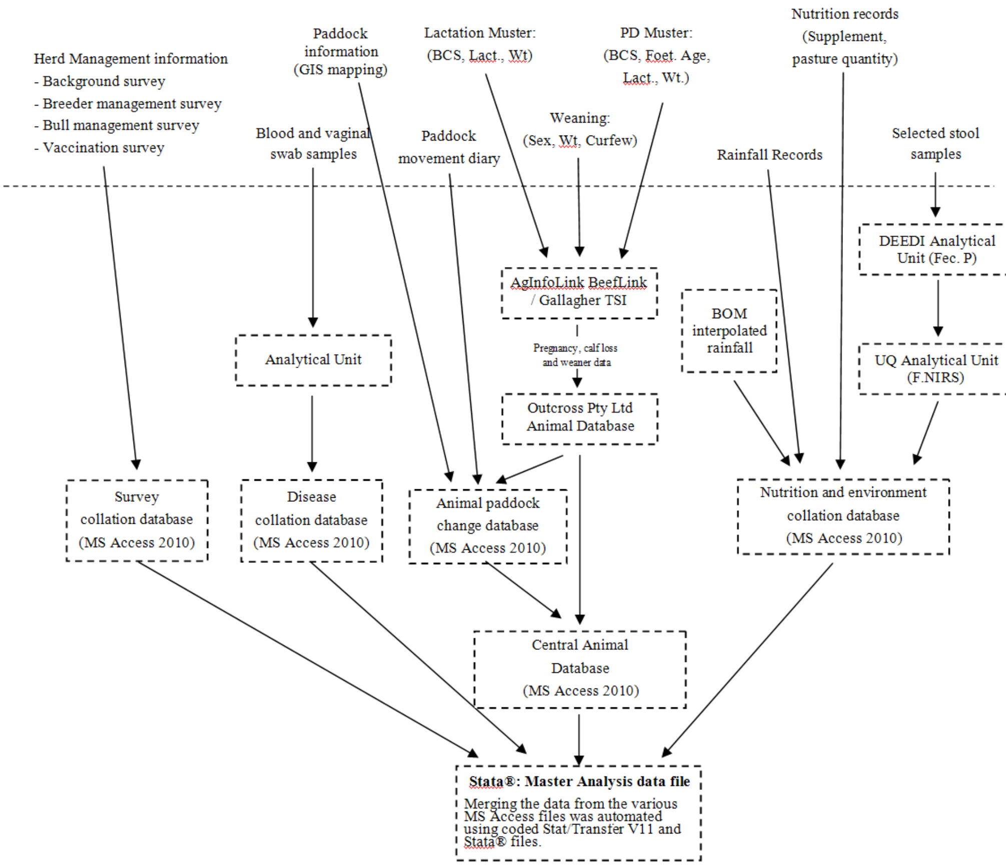

Figure 3-6: Schematic of overall data collation and management.

3.7.4.1 Data collation and cleaning of animal data

All electronically captured animal data were stored locally on a laptop and then transferred to a central server using client-server architecture managed by Outcross Performance Pty Ltd. Individuals responsible for data collection screened the data prior to its transfer to the server and notified Outcross Performance Pty Ltd of any required changes. Daily backup copies of all data files were generated within Outcross for data security.

Rules-based processes were used within the Outcross Performance Pty Ltd system to check and clean data and remove duplicate or erroneous records. Duplicate data could include things such as the data collector recording for example Lactation Status = 'not lactating' and then changing it to 'lactating'; the initial recorded Lactation Status would be removed. Erroneous data could include things such as weights that were obviously outside a normal range. Standardised summary reports defining number of cattle examined, frequency distribution of each parameter measured were generated and sent to owners/managers for checking.

Cleansed data were stored by Outcross Performance Pty Ltd as redundant copies of a Master database and increments from this database were then provided to the Cash Cow Project Manager on a monthly or bi-monthly basis for uploading into the study's central animal database.

3.7.5 Data verification

Data, particularly those within the central animal database, were extensively verified retrospectively using a number of different methods that included a large number of queries written in Microsoft® Access and contingency tables using Stata®. Potentially inaccurate or incomplete data were identified using the verification processes summarised in Table 3-9. These approaches were used to identify and resolve undetected duplicate records and situations where biologically implausible or illogical data entries indicated likely data entry errors. Where possible, these issues were resolved such that valid data were retained. In addition, a master file was maintained of animal identification records (incorporating RFID and visual tag details) that allowed traceability of records in cases where one or the other identification was not recorded on any occasion or where an animal had a RFID tag replaced.

Table 3-9: Summary of data verification methods to identify potentially inaccurate or incomplete data.

Verification issue	Method
Identify duplicate crush-side animal data	Prior to the importation of Outcross data into the central animal database, all crush-side captured heifer/cow and weaner data were queried using Microsoft® Access for data relating to the same animal on the same day. In instances where this assumption was breached, the last recorded data was assumed to be more accurate than the earlier version.
Identify duplicate muster animal data	Using a management group-level muster table in Microsoft® Access each cattle muster was assigned a purpose (branding/weaning or pregnancy diagnosis) and queries were written to identify animals that had more than one muster for the same purpose. In instances where this occurred the data was manually checked and the most biologically plausible was retained in the data.
Lost/maintain individual identification	Using a master-animal and a RFID change table in Microsoft® Access changes to the RFID were matched to historic records. Queries in Microsoft® access were written to identify animals in the master-animal table that had the same visual management tag number and resided on the same property. All identified potential duplicate master-animal records were manually checked for similarities in Year brand and overlapping muster records. If it was considered that it was the same animal, the RFID change table was updated to connect the records to the historic information.
Categorical variables	For all categorical variables contingency tables were produced showing all levels and number of records with each level e.g body condition score.
Continuous variables	For all continuous variables, minimum and maximum values were calculated to identify values outside the specified biologically plausible ranges e.g live weight.
Identify event combinations that were biologically implausible	Contingency tables, including missing values were generated in Stata® and SAS® for all event combinations to identify all implausible event combinations e.g not-detectably pregnant and recorded lactating the subsequent year.

Table 3-9: (continued) Summary of data verification methods to identify potentially inaccurate or incomplete data.

Verification issue	Method
Identify illogical sequence of events	Contingency tables, including missing values, were generated in Stata® and SAS® for all sequence event combinations to identify all illogical sequences e.g culled and present at the subsequent muster.
Identify events separated by implausible time intervals	A number of queries using Microsoft® Access, Stata® and SAS® were used to identify events separated by implausible intervals e.g the interval between two expected calving dates.

3.8 Explanatory variables

Putative risk factors were grouped into property- or herd-, property-year-, and animal-level risk factors.

3.8.1 Property or herd-level factors

Property or herd-level factors or variables can be categorised into three groups, aggregate, environmental or contextual, and group or global (Dohoo *et al.* 2009). Variables of all three types were measured in the study. Global (characteristics of the group that have no analogue at the animal-level) and environmental (characteristics of the group that have an analogue at the animal-level) herd-level variables were derived from the survey templates completed by the owners/managers. Aggregate herd-level variables are summaries of measurements made on individual animals applied at the herd-level. Details of the property or herd-level factors are presented in Table 3-10.

Table 3-10. Details of property-level factors

Variable	Detail
Country type	Southern Forest / Central Forest / Northern Downs / Northern Forest as per section 3.6.3.
Property Size (ha)	continuous variable
Property management structure	Owner manager / Private manager / Company manager / Leasee or Agistee
Duration managing enrolled property	<10 years; 10-<20 years; ≥20 years
Average annual rainfall (mm)	continuous variable
Cow herd size	<500 cows, 500 to <1000 cows, 1000 to <3000 cows and ≥3000 cows.
Average size of breeding management groups	≤100 cattle, >100-400 cattle or >400 cattle
Impact of wild dogs on herd performance	Not considered a problem; considered a problem, intermittent control only; considered a problem routine baiting used
Average age (mths) of calves at weaning	continuous variable
Mating management	Females deliberately exposed to bulls for a period less than 4 months (Control mated for ≤3 months); Females deliberately exposed to bulls for 4-7 months, typically bulls removed at PD muster and re-introduced early New Year (Control mated between 4-7 months); Females deliberately exposed to bulls for >7m of a year (Continuously (>7m) mated without segregation); Females deliberately exposed to bulls for >7m of a year with cows segregated on the basis of either lactation status or foetal age (Continuously >7m mated with segregation).
Primary mustering technique used	Use of aerial vehicles such as a helicopter or aeroplane (Air); Use of infrastructure that has been put in place to gather and hold cattle, such as trap yards (Trapping); Use of dogs/motorbikes or horses (Ground).

Table 3-10: (continued) Details of property-level factors

Variable	**Detail**
Mustering efficiency	The number of times an enrolled female was absent throughout the study calculated as a percentage of the cumulative number of animals attempted to be mustered was categorised as <5%, 5-<10% and ≥10%. An absent animal was defined as an animal that failed to be mustered but was known to be alive because it subsequently turned up at a later scheduled muster.
Heifer selection protocol	All weaned female calves retained and later exposed to bulls (No Selection); Heifer selection based on visual appraisal (Visual appraisal); Heifer selection based on estimated live weight or live weight (with or the without the use of scales) (Liveweight) gain prior to first mating .
Provision of supplemental nitrogen during the dry season (May to October)	Provided in some years; Provided in all years; Not provided.
Provision of supplemental phosphorus during the wet season (November to April)	Provided in some years; Provided in all years; Not provided.
Age cows were culled for age	Cows not culled on age; Cows culled at ≤10 years of age; Cows culled at >10 years of age
Culling rate for breeding females	The number of females culled though out the year as a percentage of those mated in the previous breeding season was calculated and categorised as <10%, 10-<15% and ≥15%.
Major source of income	Sale of weaners; Sale of feeder cattle; Sale of cows/bulls and bullocks. More than one source was allowed to be identified
Bull to female mating ratio used	<2:100 females; 2-3:100 females; ≥4:100 females

Table 3-10: (continued) Details of property-level factors

Variable	Detail
Replacement bull selection policy	*Some best practice*: at least 2 of the following used –replacement bulls vaccinated for tick fever [if required] and bovine ephemeral fever (BEF), BCS managed prior to first mating, introduced to property in cooler months, allowed ≥2 months to acclimatise prior to first mating. Note no bull breeding soundness examination (BBSE) used. *Most best practice*: replacement bulls selected on basis of having passed a veterinary BBSE and at least 2 of the following; vaccinated for tick fever [if required] and bovine ephemeral fever (BEF), BCS managed prior to first mating, introduced to property in cooler months, allowed ≥2 months to acclimatise prior to first mating *Nil best practice*: Did not meet criteria for either 'Some' or 'Most best practice'.
Herd bulls management policy	*Some best practice*: at least 2 of the following – same age bulls mated together, vaccinated for BEF annually, BCS managed prior to mating, treated for external and internal parasites annually, bulls culled at ≥8years of age. Note BBSE not included. *Most best practice*: bulls were selected on the basis of having passed BBSE and at least 3 of the following: same age bulls mated together, vaccinated for BEF annually, BCS managed, treated for external and internal parasites annually, bulls culled at ≥8years of age. *Nil best practice*: Did not meet criteria for either 'Some' or 'Most best practice'
Herd vaccination policy – bovine viral diarrhoea virus (BVDV or bovine pestivirus)	Heifers only vaccination; Whole herd vaccination; Not vaccinated
Herd vaccination policy - Vibriosis, Leptospirosis, Botulism	Categorised as either vaccinated or not vaccinated for each disease

3.8.2 *Property-year factors*

Animal-year level factors are described in Table 3-12.

Table 3-11. Details of property-year factors

Variable	**Detail**
Wet season onset	The wet season onset was derived using interpolated daily rainfall information that was downloaded from the Australian Bureau of Meteorology (BOM) using the GPS location for the paddock or homestead. The wet season onset was defined as the date at which an accumulation of 50 mm of rainfall was reached in 14 days or fewer, starting from any day after September 1 (but before March 31).
days after wet season onset to follow up rain	Using interpolated daily rainfall information for the GPS location of a paddock or homestead from the Australian Bureau of Meteorology (BOM), the number of days following the wet season onset until another major rainfall event was derived. A major rainfall event was defined as an accumulation of 50 mm of rainfall in 14 days or less.
Minimum dry season biomass	The reported average estimated minimum quantity of pasture available between May 1 to October 31 was categorised as either <2000 kg/ha or ≥2000 kg/ha
Seasonal crude protein(CP) content of the pasture	The average CP content of the pasture for the wet (November 1 to April 30) and dry seasons (May 1 to October 31) was recorded on the continuous scale. Documented threshold value of 6-8% CP were inspected based on Minson (1990) and Winks *et al.* (1979). However, these were not found to be discriminatory and subsequently re-categorised as <5% or ≥5%.
Seasonal dry matter digestibility (DMD) of pasture	The average DMD of the pasture for the wet (November 1 to April 30) and dry seasons (May 1 to October 31) was recorded on the continuous scale and subsequently categorised as either <55% or ≥55% (Jackson 2012).

Table 3-11: (Continued) Details of property-year factors

Variable	Detail
Average ratio of dry matter digestibility to dietary crude protein during dry season	The ratio of the dietary crude protein content to dry matter disability was calculated and averaged across both wet (November 1 to April 30) and dry (May 1 to October 31) seasons and categorised as either <8:1 and ≥8:1 DMD:CP (Dixon and Coates 2005).
Average wet season ratio of faecal phosphorus (FP) to metabolisable energy (ME)	The ME of the diet was calculated from the DMD using the equation ME = 0.172 x DMD − 1.707 (CSIRO 2007). The average FP:ME ratio for all samples collected during November 1 – April 30 was categorised as ≥500 mg P : 1 MJ ME or <500 mg P : 1 MJ ME.

3.8.3 Animal level factors.

Most animal-level factors were dependant on study year and are described in Table 3-12. However, year brand, breed type and hip height were fixed across the study period and were applied at the animal-level. Year brand, representing the year that the animal was branded, was used as the primary estimate of cow age. Although there was some variation in year brand policy between properties, generally the policy was for example that a No.11 branded female was an animal born in 2010-11. Breed was categorised according to estimated *Bos indicus* content: <50% *Bos indicus*; 50-75% *Bos indicus* and >75% *Bos indicus*. However, due to the category <50% *Bos indicus* content not being represented in the Northern Downs or Northern Forest country types breed type was re-categorised as <75% *Bos indicus* or ≥75% *Bos indicus*. The categories of hip-height were <125cm, 125 to <140 cm and ≥140cm.

Table 3-12. Details of animal-year factors

Variable	Detail
Cow-age class	Heifers; First-lactation cows; Second-lactation cows; Mature cow ≤ 9 years of age excluding first- and second-lactation cows); Aged cow (>9 years of age).
Age (years)	Calculated as the year in which the animal was observed minus the year that the animal was branded plus 1.
Body condition score (BCS)	BCS was assessed and scored on a 1 to 5 scale using 0.5 increments (Hunt 2006). BCS categories were ≤2.0, 2.5, 3.0, 3.5 or ≥4
Body condition score change between pregnancy diagnosis and weaning/branding	The change in body condition score between the pregnancy diagnosis muster and the subsequent weaning or branding muster was calculated and categorised as either 'lost condition', 'maintained condition' or 'gained condition'.
Liveweight	Liveweight categories were <420 kg, 420 to <500 kg and ≥500 kg for both the branding/weaning muster and pregnancy diagnosis musters.
Liveweight gain between pregnancy diagnosis and weaning/branding musters	The average daily gain was calculated and categorised as either <250g/d, 250 to 350g/d and ≥350g/d
Mustered within 2month of calving.	Based on a muster taking place between 1 month prior to and 2 months after a females expected month of calving, heifers or cows were categorised as either 1=mustered and 0=not mustered.
Average Temperature Humidity Index (THI) during expected month of calving	Using interpolated temperature and humidity data from the Australian Bureau of Meteorology (BOM) for the GPS location of either a paddock or property homestead the THI was estimated for each day using the equation sited by Hahn *et al.* (2009): *THI=0.8 x Ambient temperature+{((Relative humidity)÷100 x (Ambient temperature-14.4))+46.4}* The average THI during the expected month of calving recorded on the continuous scale. Documented threshold value of 74 and 79 were inspected based on (Thom 1959). However these were not found to be discriminatory and subsequently categorised as <72 and ≥72.

Table 3-12 (continued) Details of animal-year factors

Variable	Detail
The cumulative number of days the estimated THI exceeded 79 (Thom 1959) during the expected month of calving.	Categorised as <14 days and ≥14 days.
The cumulative number of days the maximum temperature exceeded 40°C during the expected month of calving.	Using interpolated maximum temperature data from the BOM for the GPS location of either a paddock or homestead the number of days exceeding or equal to 40°C was categorised as <14 days and ≥14 days.
Proportion of the paddock within 2.5km of permanent water at the time of calving	Categorised as <40%, 40-<70%, 70 to <90% and ≥90%.

3.9 Data for outcome variables

3.9.1 Lactation status

Annual lactation status (i.e for the approximate 12 month period between consecutive pregnancy diagnosis musters) for each animal was based on an aggregation of the lactation status records from each mustering occasion during the annual period. Animals that lactated at either one or both mustering occasions during the annual period were given an annual lactation status of 1=lactated. Animals that were recorded as 'not lactating' at both musters or were recorded as being 'not lactating' at a muster date greater than one month after the heifer or cow's expected month of calving were given an annual lactation status of dry and recorded as 0=did not lactate. A missing value was assigned if there was uncertainty as to whether the female had lactated or not.

3.9.2 Pregnancy status

Pregnancy status of animals was generally determined by manual rectal palpation of the reproductive tract by experienced cattle veterinarians who were all members of the Australian Cattle Veterinarian's National Cattle Pregnancy Diagnosis Scheme. Females were ascribed the value 1=pregnant if the animal was determined to be pregnant and 0=not pregnant if the animal was determined to be not detectably pregnant. Females that were recorded as 'not pregnant' or did not have a pregnancy status recorded and subsequently presented as lactating the following year were retrospectively assigned an annual pregnancy status of 1 (pregnant) for the previous annual period. Females that had recently calved or aborted (mid to late term) and had palpable signs of an involuting uterus (cervix enlarged, one or both horns markedly enlarged, uterine wall palpably thickened, tract hanging over the pubis) were recorded as Resolving and depending on their lactation status were considered to have experienced foetal/calf loss or had calved normally. Females with palpable abnormalities of the reproductive tract (foetal mummification or maceration, pyometra, endometritis or metritis, adhesions or abscesses, cystic ovarian disease) were recorded as Abnormal and not pregnant.

3.9.2.1 Estimated conception date and period of calving

The date of calving and date of conception following calving were estimated based on results of foetal ageing following manual rectal palpation of the reproductive tract. The predicted month of calving was calculated using estimated foetal age at the date of the pregnancy diagnosis muster and projected forward using an assumed gestation length of 287 days. As foetal age was recorded in months, it was multiplied by 30.4 days per month to estimate foetal age in days. The predicted date of conception was then estimated by subtracting the estimated foetal age (in days) from the date of pregnancy diagnosis. The accuracy of estimating foetal age is known to be lower in females greater than 5 months pregnant (O'Rourke 1994). Of those cows diagnosed pregnant, half to two-thirds of foetuses were aged within the most accurate band of 2-5 months in all country types (Table 3-13). In Southern and Central Forest, 12% and 20%, retrospectively more foetuses would have been aged within this preferred band if pregnancy diagnoses occurred one month earlier. Females within the country type Northern Forest, tended to undergo pregnancy diagnosis at later stages of gestation than other country types with 46% of foetuses aged >5 months.

Table 3-13. Distribution of estimated foetal age for pregnant cows by country type.

months Pregnant	Southern Forest			Central Forest			Northern Downs			Northern Forest		
	No. cows	%	Cum. %	No. cows	%	Cum. %	No. cows	%	Cum. %	No. cows	%	Cum. %
1	81	1	1	58	0	0	1,700	5	5	587	2	2
1.5	346	2	3	70	1	1	593	2	7	641	2	4
2	568	4	7	178	1	2	2,833	9	16	2,600	8	11
2.5	615	4	11	187	1	4	591	2	17	933	3	14
3	972	7	17	314	2	6	3,317	10	27	2,684	8	22
3.5	1,053	7	25	428	3	10	615	2	29	833	2	24
4	1,988	13	38	1,160	9	19	6,756	20	50	4,215	12	36
4.5	897	6	44	1,260	10	29	1,060	3	53	807	2	39
5	3,631	25	69	4,145	33	62	6,652	20	73	5,373	16	54
6	3,001	20	89	2,954	23	85	4,916	15	88	4,374	13	67
7	983	7	96	1,517	12	97	2,375	7	95	4,820	14	81
8	554	4	99	374	3	100	1,178	4	99	4,512	13	94
9	111	1	100	8	0	100	484	1	100	2,066	6	100

Using the predicted calving and conception dates of two consecutive years the relationship between time since calving and proportion of cows conceiving were explored to determine the most appropriate measure of reproductive performance describing efficiency of pregnancy. A commonly expressed objective for reproductive performance in beef cattle is for each cow to contribute a calf each year. Therefore, assuming a 287 day average gestation length, to achieve this objective cows must become pregnant within approximately 78 days of calving. As such, the measure describing pregnancy within 3 months of calving while lactating had been envisaged. However, descriptive analysis clearly demonstrated that pregnancy events within 3 months while lactating were particularly rare within the Northern Forest. Less than 15 cases of pregnancy within 3 months while lactating were ascribed in 45% of second-lactation cow groups.

As a small number of cases for an outcome results in analytical complications, that is popular statistical procedures such as maximum likelihood estimation of the logistic regression model strongly underestimates their probability (King and Zeng 2001). The relationship between proportion pregnant and time since calving was assessed within each cow-age class using a Cox proportion hazard model with country type as the sole predictor and adjustment for clustering at the property level. The analysis clearly demonstrated that pregnancy events within 3 months while lactating were rare, particularly in first-lactation cows within the Northern Forest (Figure 3-7). On inspecting the associations and further descriptive analysis it was determined that pregnancy within 4 months of calving while lactating was a more appropriate outcome measure of reproductive efficiency to assess the impacts of risk factors on beef cows within northern Australia.

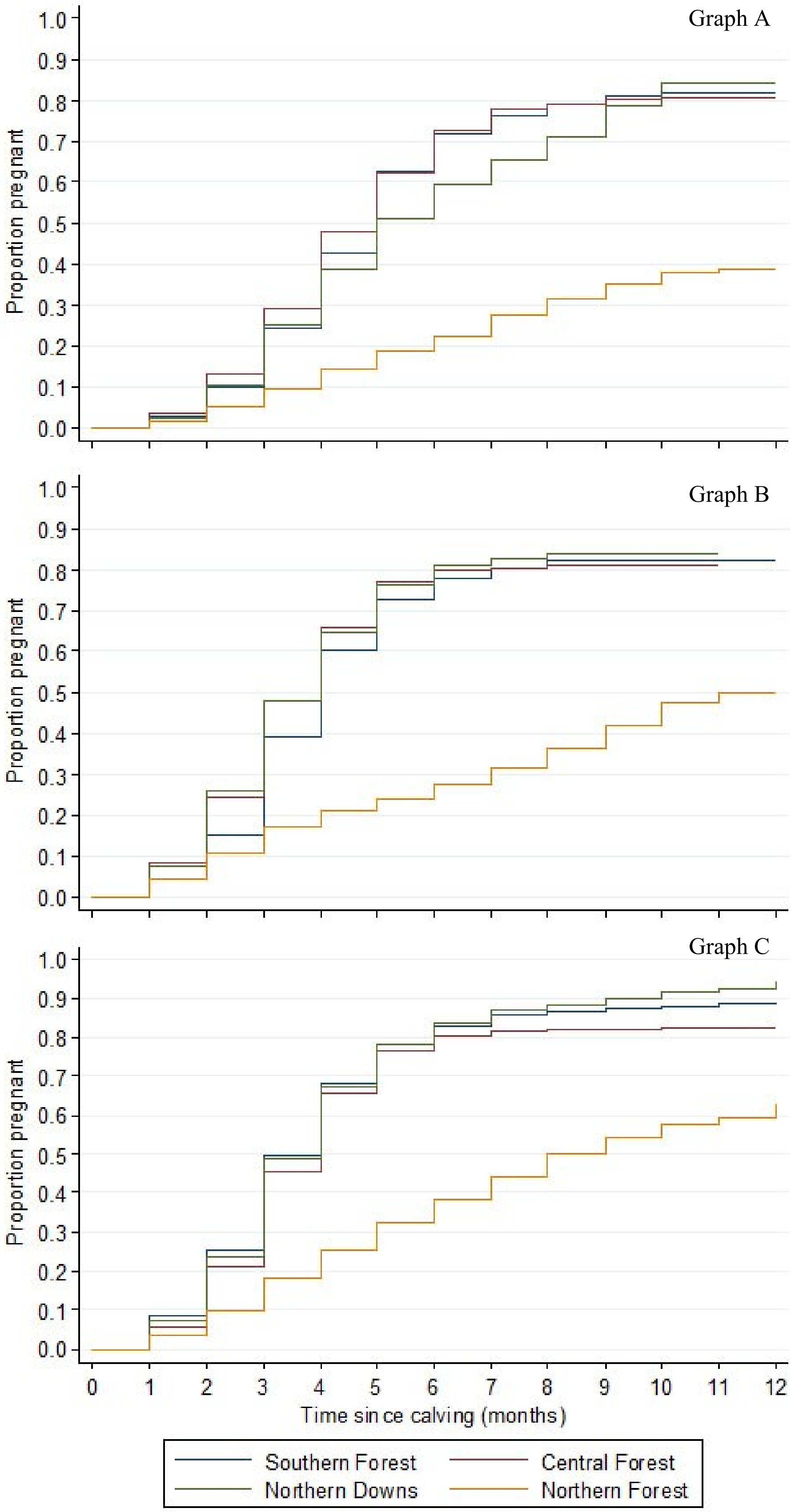

Figure 3-7: Estimate of proportion of A) first-lactation B) second-lactation and C) mature and aged cows conceiving since time of calving by country type. Based on the estimated foetal age data across two consecutive annual production cycles of 36,945 cows.

3.10 Outcome definitions

The data obtained at the branding/weaning and pregnancy diagnosis musters were used to define several reproductive outcomes for each annual production cycle (Figure 3-8). An annual production cycle was the period from the end of one pregnancy diagnosis muster to the end of the pregnancy diagnosis muster in the following year, which was conducted approximately 12 months apart.

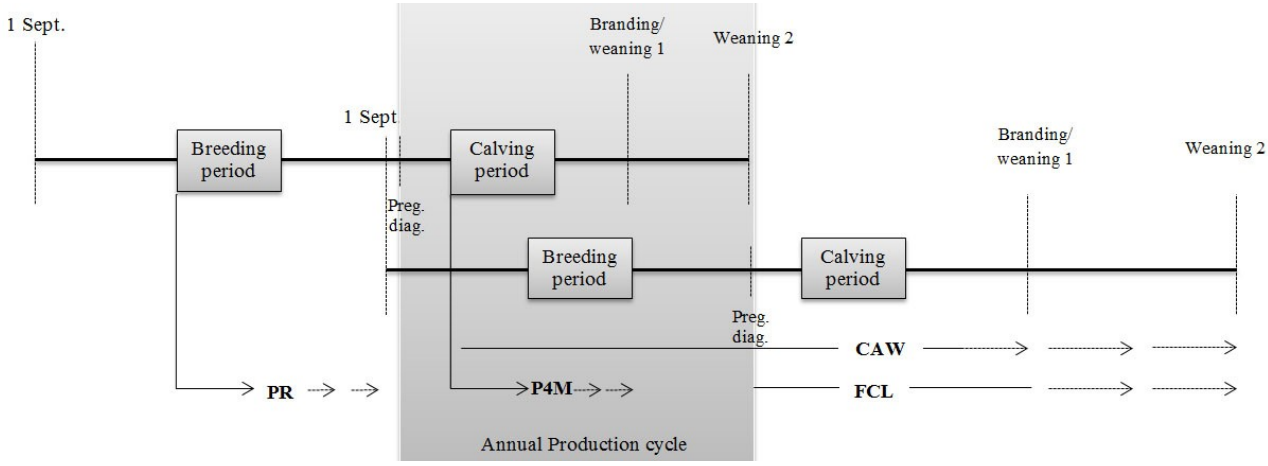

Figure 3-8: Schematic representation of data obtained at each mustering event (weaning/branding; pregnancy diagnosis) to define several reproductive outcomes (PR = annual pregnancy status, P4M = pregnant within 4 months of calving whilst lactating, FCL = loss between confirmed pregnancy and weaning, CAW = contributed a weaner).

3.10.1 Annual pregnancy status

Heifers or cows were ascribed as 1=pregnant if they conceived and were confirmed pregnant between September 1 in the previous year and prior to September 1 in the current year (this was considered an annual production cycle or period in this study). Heifers and cows were recorded as 0=not pregnant if they failed to be confirmed pregnant between September 1 in the previous year and prior to September 1 of the current year. This was updated to 'pregnant' if the animal lactated during the following year.

The threshold September 1 of the previous year was defined as the start of the annual production cycle because in continuously mated herds, females which are diagnosed pregnant after this date have the potential to contribute a weaned calf over the ensuing approximately12 months. If pregnancy diagnosis was conducted late in the previous year, conceptions estimated as occurring after September 1 were attributed to the next annual production cycle. Alternatively, advanced pregnancies detected early in the following year (weaning/branding muster) were attributed to the current annual production cycle. There were occasions where females were diagnosed non-pregnant but retrospectively were ascribed as being pregnant by cross referencing pregnancy status with subsequent lactation status.

3.10.2 Pregnant within 4 months of calving (P4M) whilst lactating

Foetal ageing in the previous and current production cycles were used to predict dates of calving and re-conception, which were then used to generate P4M. Pregnant within four months of calving (P4M) was defined as a binary variable with 0=failed to be pregnant within four months of calving and 1=pregnant within four months of calving. P4M was only determined for those cattle that were lactating at the time of conception (i.e., reared their calf).

Animals were excluded from calculation of P4M if they were recorded as having been not-pregnant in the previous annual reproductive cycle (period of approximately 12 months between consecutive annual pregnancy diagnosis musters), or if they failed to lactate after being previously diagnosed pregnant i.e experienced foetal or calf loss. Females were recorded as successfully rearing a calf if they were diagnosed as being pregnant and were then recorded as ‘lactating’ after the expected calving date. Females were recorded as having failed to rear their pregnancy if they were recorded as being not lactating (‘dry’) at the first muster after their expected calving date, provided this muster occurred greater than one month after the expected month of calving, and they were not subsequently recorded as lactating. For those females that failed to rear their previous pregnancy 66%, 71%, 55% and 55% were recorded as being pregnant within four months of calving for Southern Forest, Central Forest, Northern Downs and Northern Forest, respectively.

3.10.3 Losses between confirmed pregnancy and branding/weaning

Females were recorded as 1=failed to rear their pregnancy if they were recorded as being not lactating (‘dry’) at the first muster after the expected calving date, provided this muster occurred greater than one month after the expected month of calving, and they were not subsequently recorded as lactating. Females were recorded as 0=successfully rearing a calf if they were diagnosed as being pregnant and were then recorded as ‘lactating’ after the expected calving date. It should be noted that this measure does not include calf loss between branding and weaning and that those females that were lost to follow up during an annual production cycle were not eligible for this outcome and therefore, this outcome does not represent foetal/calf losses as a result of cow mortality.

3.10.4 Contributed a weaner

Females were recorded as 1=successfully contributing a weaner if they were diagnosed as being pregnant in the previous year and were recorded as 'lactating' at an observation after the expected calving date. Alternatively, females were recorded as 0=failed to wean a calf if they either failed to become pregnant in the previous year or were recorded as having experienced foetal/calf loss in the current year. Females that were recorded as 'not pregnant' and subsequently presented as lactating the following year were retrospectively assigned as 'pregnant' and recorded as successfully contributing a weaner. It should be noted that those females that were lost to follow up during an annual production cycle were not considered to be eligible for this outcome and therefore, this outcome does not represent cows that have failed to produce a weaned calf as a result of cow mortality.

3.10.5 Missing pregnant breeding females

Missing pregnant breeding females were defined as cows that had been enrolled in the study and diagnosed pregnant and without any record of being culled, did not contribute any further data at any of the subsequent musters. Pregnant cows classified as missing were considered to provide an indirect record of mortality, given that many extensive beef properties are not able to observe cattle in order to accurately determine mortalities. Any animal that was not present at one or more musters and failed to be recorded at any subsequent muster until the end of the project was classified as absent for the earlier musters when it had not been present. An animal could therefore only be classified as missing once the study had concluded and all possible observation periods could be reviewed to ensure that animals were not classified as missing if they had appeared at any subsequent mustering period. Animals that were known to have died were classified as missing from when they were known to have died. An absent animal was therefore any animal that failed to be yarded for an observation period but that was known to be alive because it subsequently turned up at a later mustering period. It should be noted that pregnant cows missing, is likely to be an over-estimate of mortality as it includes cows that lost their lifetime traceability due to loss of NLIS tag, or were un-reportedly relocated within the property and not sold before the end of the project.

3.11 Statistical methods

3.11.1 Data structure

The data had a natural hierarchical structure with 3 levels; represented by an annual production cycle for an individual animal, within animals (level 1), within properties (level 2), within country-type (level 3). For analyses intercept-only models with up to three nested random effects were explored. Final models were simplified to property being incorporated as a random effect to adjust for clustering of animals within each property and country-type included as a main effect. As there was only minimal replication in observations within animals (less than 2 and/or more than half of the units unreplicated) more complex repeated measures modelling was not generally performed (Dohoo *et al.* 2009).

3.11.2 General model building strategy

Variables were screened one at a time and retained for consideration in the final multivariable model if the univariable screening p-value was <0.25. Correlation matrices of all candidate explanatory variables were used to identify explanatory variables that were highly correlated (r>0.9) and where this occurred only one of the correlated variables was considered in the multivariable model. Interim animal-year level models were built by employing logistic regression analyses with adjustment for herd-level effects using a backward elimination process; starting with all candidate animal level variables that were not highly correlated. Explanatory variables measured at the management group or property level were then considered for inclusion in the multivariate models with the final animal-year level model fitted, creating candidate main effects models including both animal and property level variables.

3.11.3 Animal-year level univariable screening

Due to the number of putative risk factors, screening of risk factors was necessary. Screening of risk factors for inclusion in the multivariable model building process was based on associations between potential risk factors and the outcome of interest using a random-effects logistic regression model with Stata's -xtlogit- command, fitting herd as a random effect. The overall significance of risk factors was assessed using Wald-test P values. Risk factors were retained for consideration in the multivariable model building process if their association with the outcome was significant at the liberal p-value 0.20 (Dohoo *et al.* 2009).

The assumption of linearity of continuous variables in the logit were evaluated by inspecting both the partial residual graphs following herd-adjusted logistic regression models fitting the continuous variables as the main effect of the outcome using Stata's –lpartr- command (Hilbe 2009) and categorising the continuous variable into quartiles and graphing the estimated coefficients against the midpoints (medians) of the quartiles using Stata's –lincheck- command (Hosmer *et al.* 2013). Continuous variables that appeared to fail the assumption of linearity were categorised into two or more categories. Wherever possible, continuous variables were categorised using established threshold values. However, in some cases, where these were not found to be discriminatory, cut points were primarily determined by changes in the slope of cubic splines fitted to partial residual plots. However, if the determined cutpoints from inspection of the partial residuals plot were not represented within each country type, as it was of major interest, a further assessment of the estimated coefficients against the midpoints of the quartiles was often used to determine the final cut points.

3.11.4 Multilevel model building

Multivariable models were built using a manual stepwise approach. The starting model contained all significant ($P \leq 0.20$) property-, management group- and animal-year level risk factors on candidate variable screening being included in the model. Where starting models failed to converge, the model building process started with all candidate animal-level explanatory variables being added to the starting model and non-significant variables dropped one at a time, starting with the non-significant variable with the highest p-value. This process was continued until only significant variables remained in an interim, animal-level model. Explanatory variables measured at the management group or property level were then considered for inclusion in the model and retained if they were associated with a significant p-value, creating a candidate main effects model that included animal and management group level variables.

In some situations, models containing all significant candidate animal-year level variables failed to converge. In these instances, a forward step-wise model building process was then used, starting with the most significant animal-level explanatory variable from the screening process and then adding all other candidate variables one at a time and retaining the variable with the lowest significant p-value. This process was continued until a final animal-level model was produced and then management group-level variables were added in the same way to produce a final main effects model. This process was continued until only significant ($P \leq 0.05$) variables remained in an interim model. All omitted variables were then re-screened in the candidate main effects model, and retained if significant

Using an expert group of highly experienced northern Australian beef production research scientists and statisticians, potential confounding or intervening variables of candidate models were identified. An appraisal of effects of potential confounding variables was completed by individually including each variable into the candidate model and assessing changes in the measure of association for statistically significant variables. Confounding was considered important when odds ratios for statistically significant variables changed by >20-30% (Dohoo *et al.* 2009) and the variable was included in the final main effects model.

Biologically plausible two-way interactions were then considered and retained if they were associated with a significant p-value and an interpretable association based on assessment of marginal means and plots of effects. Country type was forced into all models and two-way interactions considered between country type and other explanatory factors in the model, because of specific interest in the effects of region that were being represented by country type.

3.11.5 Variance components

The intraclass correlation coefficient for each outcome was calculated as:

$$\frac{Var_{Null\ Model}}{(Var_{Null\ Model} + 3.29)} \qquad \text{Equation 1}$$

where $Var_{Null\ Model}$ is the random intercept variance for the null model and 3.29 = π2/3 (Snijders and Bosker 1999).

The proportion of outcome variance that was 'explained' by the fixed part of the model was calculated for each final model as:

$$\frac{Var_{Null\ Model}}{(Var_{Linear\ Predictor} + Var_{Final\ Model} + 3.29)} \qquad \text{Equation 2}$$

Where:

$Var_{Linear\ Predictor}$ is the variance of the predicted logits from the fixed part of the model and

$Var_{Final\ Model}$ is the random intercept variance for the final model (Snijders and Bosker 1999).

The proportions of outcome variation that were unexplained at the property- and animal-year levels, respectively, were calculated for each final model (Snijders and Bosker 1999) as:

$$\frac{Var_{Final\ Model}}{(Var_{Linear\ Predictor} + Var_{Final\ Model} + 3.29)} \qquad \text{Equation 3}$$

and

$$\frac{3.29}{(Var_{Linear\ Predictor} + Var_{Final\ Model} + 3.29)} \qquad \text{Equation 4}$$

3.11.6 Model checking

The overall goodness-of-fit of the multivariable model was assessed using Hosmer-Lemeshow goodness-of-fit tables and statistics (Hosmer *et al.* 2013). The Hosmer-Lemeshow goodness–of–fit test compares the observed number of cases to the expected number as determined from the statistical model, using groups based on deciles of estimated probabilities. As the number of covariate patterns was high relative to the number of observations, this statistic was assumed to approximate a chi-square distribution with 8 degrees of freedom (Hosmer *et al.* 2013). However, it has also been demonstrated that significance is likely in datasets of large sample sizes when a chi-square distribution with 8 degrees of freedom is assumed (Paul *et al.* 2013).

To assess the general usefulness of models, the predictive ability of the models were assessed by computing the classification statistics of models after selecting an appropriate cut point that was determined following an inspection of two-graph receiver operating curves versus the probability cut points. Model discrimination was also assessed using the area under the receiver operating characteristics curve, estimated using the –rocfit- command in Stata (Stata 13.1 for Windows, Stata Corporation, College Station, Texas USA).

The fit of the multivariable model was evaluated and observations that did not fit the model well (outliers) or having an undue influence on the model were identified. Outliers were identified by an analysis of the residuals and models with and without the influential observations were compared.

3.11.7 Marginal effect estimates

The final statistical model output was used to predict the point estimate of the probability (expressed as a percentage) of the outcome occurring for the levels of each explanatory variable included in each final model. Adjusted predictions were estimated assuming the levels of each factor covariate were equally likely (balanced), including interaction terms. The statistically minded reader will note that the confidence intervals are symmetric around the predicted means even though the predictions are derived from a logistic regression model. Standard errors were obtained by the delta method (Xu and Long 2005), which is a general approach for computing confidence intervals for functions of maximum likelihood estimates. The delta method takes a function that is too complex for analytically computing the variance, creates a linear approximation of that function, and then computes the variance of the simpler linear function that can be used for large sample inference. The variance of the simpler approximation is used for constructing the confidence interval. The 95% confidence limits computed by the delta method can include values that exceed the range of the statistic being estimated (i.e. <0 or >1).

Chapter 4 Nutritional, breeding and herd health management practices in commercial beef breeding herds in northern Australia.

4.1 Abstract.

An observational study was completed in commercial north Australian beef breeding herds to determine and quantify the major associations between herd management choices, nutritional or environmental factors and individual cow attributes and measures of reproductive performance. At the commencement of the study 78 herd owners/managers of commercial beef properties conducted a face to face paper-based survey questionnaire examining the nutritional, breeding herd and herd health management practices and policies. Using four broad regional categories, this paper presents descriptive summaries of the management practices and nutritional conditions of cooperating herds of the Cash Cow project.

Large variation existed within and between country type for size of properties, paddocks and breeding herds, and their degree of development. Corporately owned properties generally located within the Northern Downs and Forest compared to Southern and Central Forest and tended to have more frequent changes in management.

Nearly half of the study properties within the Northern Forest aspired to increase breeding herd numbers in excess of 10% and were less likely to cull breeders based on age, compared to other country types. In some instances, further investment in additional watering points was potentially able to support this increase with less than 15% of paddock areas within 2.5 km from water observed for some paddocks with stocking rates aligned to estimated safe carrying capacity.

Pasture quality during the dry season was likely to be approaching minimum maintenance requirement of cows for approximately 50% of properties in each country type. However, differences in amount of available P between country types, as indicated by the ratio of faecal phosphorus to metabolisable energy during the wet season, was likely to limit animal production if supplemental phosphorus was not provided for many north Australian properties, particularly those located within the Northern Forest. The nutritional challenges described for the Northern Forest were consistent with the estimated 50 kg lower expected annual growth of yearling steers by herd managers, when compared to other country types.

Properties within the north-western regions of northern Australia generally tended to mate bulls at higher rates for longer periods. The use of best practice processes for the selection of replacement bulls and management of herd bulls were lowest within the Northern Forest and highest within the

Central Forest. Across all study participants there was moderate use of best practice processes with respect to bull selection and management.

4.2 Introduction

The north Australian beef herd represents sixty percent of the national beef herd and there are 9000 beef producing properties in northern Australia (Martin *et al.* 2013). The beef industry in many parts of northern Australia has historically been an extensive, low input system, with relatively low outputs per unit land area. The primary production activities conducted on northern beef properties are breeding, and growing and fattening weaned cattle (O'Rourke *et al.* 1992; Sullivan 1992; Bortolussi *et al.* 2005b). Generally, properties within the more intensively managed areas of Southern Queensland primarily breed and fatten cattle while properties within the more extensive areas of north-western Australia primarily are breeding only (O'Rourke *et al.* 1992). Properties within the Northern Territory, northern Western Australia and parts of northern Queensland sell most, if not all their cattle to the live export market (Bortolussi *et al.* 2005b), whereas elsewhere producers have more flexibility being able to sell slaughter cattle to either the domestic or export markets and as well as some cattle on occasions to the live export market..

Rainfall across northern Australia is highly variable between seasons with the majority (~80%) of the annual rainfall occurring during the wet season (Nov-Apr) (Lo *et al.* 2007). The 'onset', or transition to the wet season tends to vary between years and between regions. The timing of the 'onset' or 'green break' and the duration of the wet season supporting green pasture growth is highly correlated with animal production (Balston and English 2009).

There is large variation in the reproductive performance of northern beef cattle herds (O'Rourke *et al.* 1992; Cowley *et al.* 2014). Numerous studies have identified herd, management group and animal-level factors affecting reproductive performance (Hasker 2000) and many of these have been recently comprehensively reviewed (Burns *et al.* 2010). In order for herd managers and industry stakeholders to prioritise management and investment, there is increasing interest in the determination and quantification of the major factors responsible for lower than expected reproductive performance. With the aim to describe reproductive performance of commercial beef herds, determine and quantify the major associations between reproductive outcomes and herd management practices, nutritional and environmental factors and individual cow attributes a study using population-based methodology was conducted in north Australian commercial beef breeding herds between 2007 and 2011. This study describes the demographics and the nutritional, breeding and herd health management practices and policies employed by study participants, known hereafter as the Cash Cow project.

4.3 Materials and methods

The target population for the study was beef breeding herds within northern Australia and involved 78 commercial beef properties (Figure 4-1). At the commencement of the study, a face to face survey was completed by each cooperating herd owner/manager with assistance from a regional project co-ordinator (N=6) to ensure a uniform interpretation of the questions and responses. Ethical clearance for the study was approved by The University of Queensland Animal Ethics Committee (Production and Companion Animal; AEC approval numbers SVS/756/08/MLA and SVS/729/07/MLA).

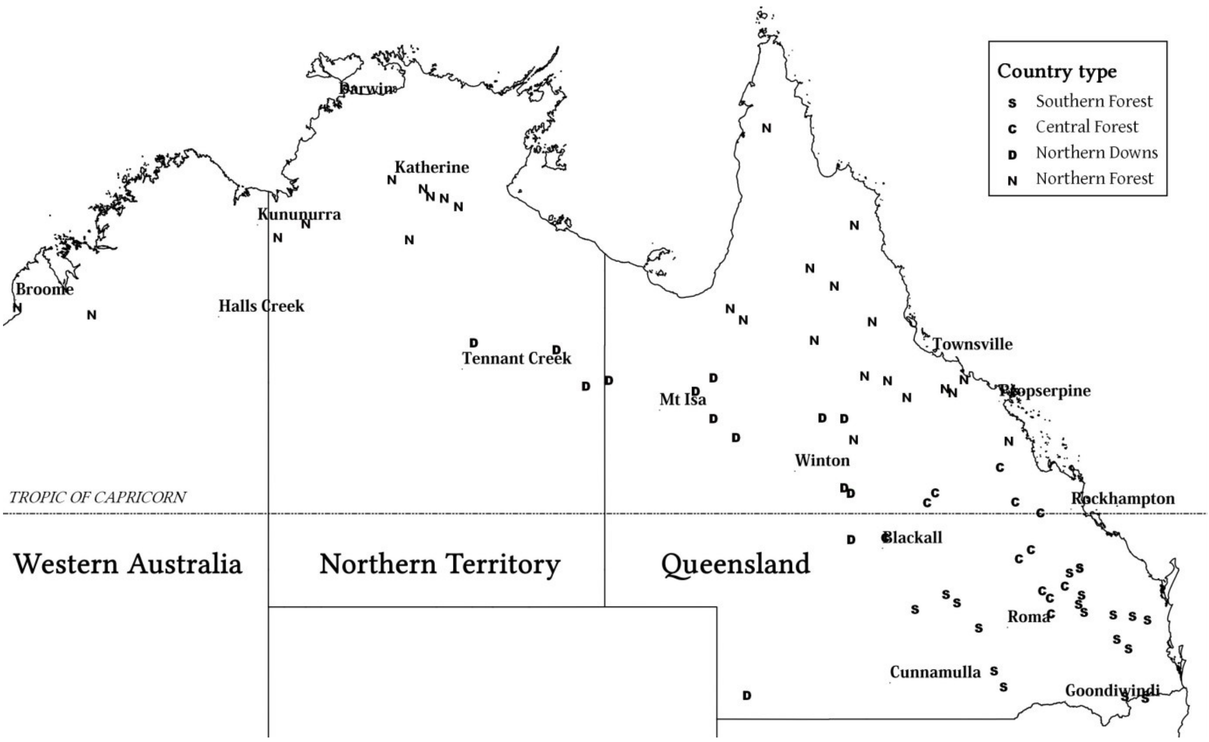

Figure 4-1. Location of cooperating properties by country type.

As survey participants were selected on the basis of participating in the Cash Cow project (McGowan *et al.* 2014) it is not a truly random sample of north Australian beef breeding producers, and this selection bias is acknowledged. However, the producers enrolled in the Cash Cow project were considered to represent a broad cross-section of the north Australian beef breeding industry.

In addition to the survey, there was on-going assessment of grazing resources utilised by study animals which included mapping of paddock infrastructure using GPS software (such as ArcView), longitudinal nutritional profiling of pasture quality and quantity, and using the GPS location of a paddock or homestead daily interpolated environmental data (such as temperature and rainfall) was obtained from the Australian Bureau of Meteorology (BOM).

4.3.1 Survey Structure

The survey was conducted to define property demographics, management of grazing lands and breeding female management, including management of bulls and infectious diseases. The format of the questions was mostly tick-a-box allowing one response per question. Questions concerning property details were mostly formatted as single line text responses or numeric values.

The survey was made up of four sections:

i. general property information: property area, location, herd size, ownership structure, main beef production activity and estimated annual beef production from the pastures utilised by enrolled breeding groups.
ii. breeding female management: herd management practices and policies of the producer/owner including duration and timing of mating period, age at and timing of weaning, culling and selection criteria, and nutritional management
iii. bull management: bull management and selection practices and policies including selection and culling criteria, relocation management, nutritional and health management
iv. herd vaccination policy: breeding herd vaccination policies for bovine viral diarrhoea virus (BVDV) infection, vibriosis, leptospirosis and botulism

4.3.2 Regionalisation of properties

Properties were assigned to one of four broad country types following a subjective assessment of the production potential of the grazing land and cross-referencing with pasture and vegetation descriptions reported by the herd managers. Properties with forested land-types with fertile soils in the central and south-east regions of Queensland were differentiated by being outside (Southern Forest) and within (Central Forest) the northern Brigalow Forest. In the northern areas of Queensland, Northern Territory and Western Australia, properties with land types that were predominantly large treeless black soils plains (Northern Downs) were segregated from those with forested land-types and low fertility soils (Northern Forest).

4.3.3 Average annual growth of yearling steers

Property owners/managers were asked to provide an estimate of what they would expect the mean annual growth of yearling steers would be if they grazed the pastures the enrolled management groups would graze.

4.3.4 Pasture quality

Wet and dry season pasture quality assessments were based on faecal Near Infrared Spectroscopy (F.NIRS) and wet chemistry faecal phosphorus (FP) analyses conducted on dung samples collected in January, March, May, August and November. Using F.NIRS dry matter digestibility (DMD) and crude protein content (CP) were determined, and faecal phosphorus (P) content was estimated according to (Zarcinas *et al.* 1987; Coates 2004). Property pasture quality estimates were summarised by averaging data across both wet (November 1 to April 30) and dry (May 1 to October 31) seasons. Following estimation of the metabolisable energy (ME) content of the pasture using the equation $\mathrm{ME} = 0.172 \text{ x } \mathrm{DMD} - 1.707$ (CSIRO 2007), the ratio of FP:ME was calculated for each sample (expressed as mgP/MJME) and averaged across the wet season (November 1 to April 30) for each property.

4.3.5 Paddock area and distance to water

Paddocks grazed by study groups were digitised from either paper based maps, satellite maps, existing digital maps, or GPS points by project regional coordinators. Using the resulting digitised maps paddock areas were estimated using the ArcMap GIS program. Paddock areas within 1.5, 2.5, and >2.5 km of permanent water points were estimated using AgData's Phoenix mapping software. Where short duration grazing using a series of small paddocks (e.g cell grazing) was practised those paddocks were classified as one paddock.

4.3.6 Average long term wet season onset

The long term wet season onset was derived for each property using 100 year interpolated daily rainfall information downloaded from the Australian Bureau of Meteorology (BOM) using the GPS location of either a utilised paddock or the property owners/managers residence on the property. The wet season onset was defined as the date at which an accumulation of 50 mm of rainfall was reached in 14 days or fewer, starting from any day after September 1 (but before March 31). The date of wet season onset in 50% and 75% of years was derived for each individual property and averaged across properties within country types to describe an overall green date for the country type.

4.3.7 Mating management

Mating management was categorised as follows: Control mated ≤3 months - females deliberately exposed to bulls for a period ≤3 months; Control mated 4-7 months - females deliberately exposed to bulls for 4-7 months (includes properties where bulls were removed at the 2nd annual muster and re-introduced early in the New Year); Mated >7 months without cow segregation - females continuously exposed to bulls for greater than 7 months of the year; Mated >7 months with cow segregation - females continuously exposed to bulls for greater than 7m of the year with cows segregated on the basis of either lactation status or foetal age.

4.3.8 Bull selection and management.

Bull management was categorised according to the level of best practice management applied to the selection of replacement bulls, and annual bull management. Replacement bull selection was categorised as follows: *Some best practice*: at least 2 of the following used –replacement bulls vaccinated for tick fever, if required, and bovine ephemeral fever (BEF), BCS managed prior to first mating, introduced to property in cooler months, allowed ≥2 months to acclimatise prior to first mating. No bull breeding soundness examination (BBSE) used. *Most best practice*: replacement bulls selected on basis of having passed a veterinary bull breeding soundness examination (BBSE) and at least 2 of the following; vaccinated for tick fever, if required, and bovine ephemeral fever (BEF), BCS managed prior to first mating, introduced to property in cooler months, allowed ≥2 months to acclimatise prior to first mating; *Nil best practice*: Did not meet criteria for either 'Some' or 'Most best practice'..

Management of herd bulls was categorised as follows: *Some best practice*: at least 2 of the following – same age bulls mated together, vaccinated for BEF annually, BCS managed prior to mating, treated for external and internal parasites annually, bulls culled at ≥8years of age; *Most best practice*: bulls selected on the basis of having passed BBSE and at least 3 of the following: same age bulls mated together, vaccinated for BEF annually, BCS managed, treated for external and internal parasites annually, bulls culled at ≥8years of age.; *Nil best practice*: Did not meet criteria for either 'Some' or 'Most best practice'.

4.3.9 Data management and analysis

The main form of data analysis was simple descriptive statistics, frequencies by categories and cross-tabulation by country types. All analyses were completed using Stata for Windows (Version 13.1, StataCorp, College Station, TX, USA).

4.4 Results

Surveyed owners/herd managers of the 78 properties enrolled in the Cash Cow project managed in excess of 9 million hectares of land and 250,000 breeding females. Expected mean annual growth of yearling steers was much lower for the Northern Forest compared to the other country types, and had the greatest variation between properties (Table 4-1). The proportion of owners/herd managers that wanted to increase the size of their breeding herd was greatest in the Northern Forest. Across all country types, the major sources of income were the sale of weaned and feeder cattle. However, the proportion of properties that indicated the sale of bullocks as a major source of income was higher for country types with higher estimated mean annual growth of yearling cattle.

Summary statistics for derived nutritional and environmental factors are presented in Table 4-2. The mean reported annual rainfall was greatest within the Northern Forest, while the variability of annual rainfall was greatest in the Southern Forest. Onset of the wet season was between November and December. Paddock size varied enormously both within and across country types. However, whereas in the Southern and Central Forest the majority of grazing area was within 2.5km of a permanent watering point, in the Northern Downs and Forest only about three-quarters of the grazing area was within 2.5km of water. Mean percentage dry matter digestibility and crude protein were similar across country types for the wet and dry seasons, however mean wet season crude protein percentage tended to be lower in the Northern Forest. The mean wet season FP:ME across the study period measured for properties in the Northern Downs and Northern Forest was <300 mg P per MJ ME for 15% (95% CI, 4-47%) and 17% (95% CI, 7-36%) of properties.

Table 4-1. Summary of property demographics and management by country type.

	Southern Forest	Central Forest	Northern Downs	Northern Forest
Property Size (km^2; 1km^2 = 100 ha)				
N=	16	13	13	23
Mean	652	168	3,306	1,528
Median	60	162	364	1,250
Range	12–8,900	49–410	130–16,118	26–4,500
Proportion (%) of properties with different ownership and management structure				
N=	22	12	13	30
Owner/Manager	18 (82%)	6 (50%)	8 (62%)	10 (33%)
Private Manager	1 (5%)	4 (33%)	0 (0%)	6 (20%)
Corporate Manager	3 (14%)	2 (17%)	5 (38%)	12 (40%)
Leasee/Agistee‡	0 (0%)	0 (0%)	0 (0%)	2 (7%)
Duration managing enrolled property				
N=	14	12	7	21
<10 years	6 (43%)	7 (58%)	5 (71%)	18 (86%)
10-<20 years	2 (14%)	3 (25%)	2 (29%)	2 (10%)
≥20 years	6 (43%)	2 (17%)	0 (0%)	1 (5%)
Breeding herd size (number of cattle)				
No. responses	18	13	13	23
Mean	972	1,192	8,737	4,614
Median	572.5	1,200	2,400	3,700
Range	280-8,056	350-3,000	550-44,000	220-15,097
Proportion (%) of properties wishing to decrease, maintain or increase herd size				
N=	21	13	13	30
↓≥10%	3 (14%)	1 (8%)	2 (15%)	2 (7%)
↓<10%	1 (5%)	0 (0%)	1 (8%)	1 (3%)
Maintain	12 (57%)	9 (69%)	9 (69%)	10 (33%)
↑<10%	0 (0%)	0 (0%)	0 (0%)	3 (10%)
↑≥10%	5 (24%)	3 (23%)	1 (8%	14 (47%)
*Major sources of income**				
No. responses	16	13	13	25
Sale of Weaners	5 (31%)	4 (31%)	2 (15%)	14 (56%)
Sale of Feeder cattle	7 (44%)	4 (31%)	8 (62%)	8 (32%)
Sale of Cows/Bulls	7 (44%)	4 (31%)	5 (38%)	9 (36%)
Sale of Bullocks	9 (56%)	8 (62%)	3 (23%)	4 (16%)
Estimated mean annual growth of yearling steers (kg)				
No. responses	12	6	5	17
Mean	195	179	168	116
Median	200	181.5	160	105
Range	140-250	140-220	150-200	75-220

* More than one major source of income was nominated by some respondents; † A bullock is a mature desexed male; ‡ Owners of cattle who pay for access to grazing resources.

Table 4-2. Summary statistics for derived nutritional and environmental factors by country type

Variable	Southern Forest	Central Forest	Northern Downs	Northern Forest
Reported annual rainfall (mm)				
N=	12	7	4	15
Mean	588	611	461	916
Median	650	635	408	750
Range	175-825	520-700	350-680	500-2,800
Long term wet season onset (1st Sep – 31st Mar)				
N=	19	13	12	28
Mean date	3 Nov.	12 Nov.	25 Dec.	8 Dec.
Mean 75/100 yr date	13 Nov.	23 Nov.	1 Jan.	12 Dec.
*Paddock size (ha)**				
N=	82	61	80	59
Mean	505	860	6,857	4,052
Median	415	714	2,153	2,611
Range	17-4,550	63-2,802	370-71,160	202-16,387
Proportion (%) of paddock area within 2.5km grazing radius of water point†				
N=	89	61	79	60
Mean	96	95	78	79
Median	100	100	94	96
Range	19-100	23-100	6-100	12-100
Dry season crude protein (%)				
N=	21	13	13	30
Mean	6.8	5.8	6.2	5.7
Median	6.1	5.9	5.5	5.7
Range	4.4-14.1	5.3-6.4	4.8-12.5	3.9-8.0
Dry season dry matter digestibility (%)				
N=	21	13	13	30
Mean	53	52	54	52
Median	52	52	53	52
Range	48-65	50-55	52-59	49-56
Wet season crude protein (%)				
N=	21	13	13	29
Mean	9.4	8.3	8.4	7.6
Median	9.4	8.1	8.5	7.7
Range	7.5-11.8	7.6-10.7	6.6-10.5	5.0-9.5
Wet season dry matter digestibility (%)				
N=	21	13	13	29
Mean	58	58	58	55
Median	58	58	57	56
Range	54-62	56-60	55-60	50-59
Wet season FP:ME (mgP/MJME)				
N=	21	13	13	29
Mean	627	619	418	359
Median	557	540	389	347
Range	364-1080	421-1058	233-617	232-529

* Three uncharacteristically large paddocks drastically skewed the data within Southern Forest and were omitted from the analysis. When included the mean paddock area was 1,448 ha and ranged between 17- 46,437 ha;
† Data derived from GPS mapping

Responses to questions examining the management of the breeding herd and bulls on enrolled properties are summarised and presented in Table 4-3 and Table 4-4. There were major differences between country types in estimated percentage of *Bos indicus* content in the breeding females. Whereas the majority of females had greater than or equal to 75% *Bos indicus* content in the Northern Forest, in the Southern Forest the majority of females had less than 50% *Bos indicus* content. Bulls were typically exposed for longer and at a higher ratio in the Northern Forest than other country types. The typical size of breeding management groups was usually greater and higher use of aircraft to muster management groups within the Northern Downs and Forest when compared to Southern and Central Forest. The reported mustering efficiency was similar in the Northern Downs to Southern and Central Forest, however lower mustering efficiency was reported for the Northern Forest. The regular use of dry and wet season supplements was greatest in the Northern Forest and surprisingly low within the Northern Downs. The median weaning age was consistent across country types. However, progeny were sometimes weaned at older ages in the Southern Forest and more properties varied the time of weaning based on seasonal conditions within the Southern and Central Forest when compared to other country types.

Table 4-3. Summary statistics of breeding herd management by country type

	Southern Forest	Central Forest	Northern Downs	Northern Forest
Proportion (%) of properties with breeding females of different Bos indicus content				
N=	21	13	13	31
<50% Bos indicus	14 (67%)	3 (23%)	1 (8%)	0 (0%)
50 to <75% *Bos indicus*	4 (19%)	8 (62%)	9 (69%)	4 (13%)
≥75% Bos indicus	3 (14%)	2 (15%)	3 (23%)	27 (87%)
Proportion (%) of properties with different typical sizes of management groups(number of cattle)				
N=	21	13	13	31
<150	9 (43%)	4 (31%)	3 (23%)	0 (0%)
150 to <400	11 (52%)	9 (69%)	6 (46%)	22 (71%)
≥400	1 (5%)	0 (0%)	4 (31%)	9 (29%)
Proportion (%) of properties with different mating management				
N=	19	13	13	30
Mated for <3m	8 (42%)	5 (38%)	5 (38%)	1 (3%)
Mated for 4-7m	8 (42%)	8 (62%)	3 (23%)	10 (33%)
Mated for >7m	3 (16%)	0 (0%)	2 (15%)	18 (60%)
Mated for >7m with cow segregation	0 (0%)	0 (0%)	3 (23%)	1 (3%)
Proportion (%) of properties that culled breeding females on the basis of age				
N=	18	11	10	26
Yes	18 (100%)	10 (91%)	8 (80%)	20 (77%)

* Heifers and cows segregated based on either predicted month of calving or lactation status.

Table 4-3. (Cont.)

	Southern Forest	Central Forest	Northern Downs	Northern Forest
Age breeding females typically culled (years)				
N=	18	10	8	20
Mean	10.2	9.9	10.1	10.1
Median	10	10	10	10
Range	9-12	8-12	8-12	8-12
Age at weaning (months)				
N=	16	10	7	23
Mean	7.4	5.6	6.4	5.6
Median	7	6	7	6
Range	4.5-11	4-7	5-8	3-8
Proportion (%) of properties that varied the time of weaning based on seasonal conditions				
N=	17	11	11	24
Yes	13 (76%)	9 (82%)	5 (45%)	15 (63%)
Proportion (%) of properties that routinely provided nutritional supplements				
N=	21	13	13	31
Dry season (N)	11 (52%)	6 (46%)	4 (31%)	27 (87%)
Wet season (P)	6 (29%)	5 (38%)	4 (31%)	20 (65%)
Mustering technique				
No. responses	19	13	13	26
Ground (horses/vehicles)	15 (79%)	8 (62%)	5 (38%)	4 (15%)
Air (helicopter, fixed-wing)	3 (16%)	5 (38%)	8 (62%)	20 (77%)
Trapping†	2 (11%)	1 (8%)	0 (0%)	8 (31%)
Reported mustering efficiency‡				
N=	19	13	13	26
Mean	97%	97%	98%	89%
Median	99%	98%	98%	90%
Range	90-100%	90-100%	90-100%	70-100%
Proportion (%) of properties with different vaccination policies for control of BVDV infection				
N=	19	11	13	28
Not vaccinated	14 (74%)	10 (91%)	12 (92%)	28 (100%)
Heifers only vaccinated	2 (11%)	1 (9%)	1 (8%)	0 (0%)
Proportion (%) of properties vaccinating heifers prior to first-mating to control:				
N=	19	12	13	28
Vibriosis	1 (5%)	1 (8%)	1 (8%)	4 (14%)
Leptospirosis	11 (58%)	7 (58%)	0 (0%)	5 (18%)
BVDV infection	5 (26%)	1 (8%)	1 (8%)	0 (0%)
Botulism	2 (11%)	4 (33%)	6 (46%)	22 (79%)
Proportion (%) of properties vaccinating cows to control :				
N=	19	12	13	28
Vibriosis	1 (5%)	1 (8%)	0 (0%)	0 (0%)
Leptospirosis	7 (37%)	7 (58%)	0 (0%)	2 (7%)
BVDV infection	3 (16%)	1 (8%)	0 (0%)	0 (0%)
Botulism	1 (5%)	4 (33%)	8 (62%)	22 (79%)

† Cattle can be passively mustered by trap yards set up at points of enticement ie water or supplement. A common technique for mustering in timbered country or for capturing feral animals.
‡ Respondents estimate of percentage of cattle within a herd that are successfully mustered at a mustering event.

Table 4-4. Summary of bull selection and management

	Southern Forest	Central Forest	Northern Downs	Northern Forest
Bull to Female mating ratio (per 100 females)				
N=	20	13	13	26
Mean	2.9	3.1	3.1	3.5
Median	3.0	3.0	3.0	3.8
Range	1.5-5.0	2.5-5.0	2.0-5.0	2.0-5.5
Proportion (%) of properties vaccinating bulls to control:				
N=	19	12	13	22
Vibriosis	9 (47%)	9 (75%)	11 (85%)	20 (71%)
Leptospirosis	6 (32%)	5 (42%)	0 (0%)	1 (4%)
BVDV infection	1 (5%)	1 (8%)	0 (0%)	0 (0%)
Botulism	1 (5%)	3 (25%)	6 (46%)	22 (79%)
Replacement bulls managed using best practice protocols				
N=	18	13	12	27
Nil	6 (33%)	0 (0%)	3 (25%)	17 (63%)
Some	5 (28%)	4 (31%)	3 (25%)	2 (7%)
Most	7 (39%)	9 (69%)	6 (50%)	8 (30%)
Herd bulls managed using best practice protocols				
N=	18	13	12	27
Nil	1 (6%)	0 (0%)	5 (42%)	12 (44%)
Some	9 (50%)	3 (23%)	3 (25%)	7 (26%)
Most	8 (44%)	10 (77%)	4 (33%)	8 (30%)

4.5 Discussion

The mean property size varied widely within and between the country types. Property sizes were largest within the Northern Downs and Northern Forest country types and these findings are not dissimilar to those reported by O'Rourke *et al.* (1992) and Bortolussi *et al.* (2005b). Properties larger in size were commonly managed by a corporate manager and less likely to be managed by their owners. Within the Northern Downs and Forest, where the percentages of properties managed by corporate managers was highest, the duration the current manager had been managing the property was lowest and is potentially partially explained by corporate practice of relocating property managers within the corporation on a regular basis. Similarly in the Central Forest, where the proportion of managers of privately owned properties was highest, the duration since the last change in management was comparable to that of the Northern Downs and Forest. This potentially suggests that it is less common for mangers to remain on an individual property for in excess of 10 years unless they own the property. It is also interesting to note that in the Northern Forest, where the nutritional and environmental challenges are likely to be the greatest for beef cattle production, the frequency of management changes appeared to be the greatest. While managers within this country type in particular, may take longer to attain an in depth understanding of the cattle and property dynamics, due to the heightened nutritional and environmental stressors, and increased property size. Therefore, moving managers too frequently may be counterproductive. The Southern Forest contrasted with other country types as 82% of properties were managed by their owners and the last change in management occurred ≥20 years in 43% of properties.

Generally, the size of the breeding herd and paddock size was correlated with property size and is cofounded by the selection protocol of survey participants as all study participants were required to be primarily beef breeding enterprises. The median breeding herd size was largest for the Northern Forest and smallest for the Southern Forest. However, within the Northern Downs country type, very large breeding herd sizes were observed for corporate enterprises within the Barkly Tableland with up to 44,000 breeding females and is consistent with large land holdings of large carrying capacity as Mitchell grass pastures in good condition can sustain stocking rates up to 13 animal equivalent units per square kilometer in 50% of years (Walsh and Cowley 2011).

Installing additional water points is a method of increasing the safe carrying capacity of enterprises by accessing underutilised areas and distributing grazing more widely across the landscape and reducing the risk of overgrazing pasture around watering points (Hunt *et al.* 2007). Comparable proportions of paddocks grazed within 2.5km of water were estimated for the Northern Downs and Forest and overall represented a high level of development for most paddocks. However, within these country types opportunities appear to exist for further development with on average approximately 20% of paddocks available for further utilisation and is consistent with findings reported by Cowley *et al.* (2014) who summarised Katherine and Barkly regions as utilising 75% and 89%, respectively of surveyed property area. Correspondingly, survey respondents within the Northern Forest had the greatest desire to increase current breeding numbers, with 47% of producers aiming to increase breeding herd numbers by ≥10%, reduced culling of breeding females on age and a higher proportion of retained cows non-pregnant for re-mating. Investment in additional watering points potentially could support this increase in cattle if the current stocking rates are based on the pasture currently accessible. In contrast to the Northern Forest, a greater proportion of survey respondents within Northern Downs despite having similar proportions of paddocks within 2.5 km of water, wanted to maintain their current breeding herd size and potentially reflects greater season variability.

The use of aircraft to muster cattle was consistent with size of property and paddocks as they offer efficiencies in mustering costs over other techniques due to a reduction in labour and time as well as being able to access difficult country to muster. The most use of aircraft was in the Northern Forest and is likely to be explained by size of paddocks, dense vegetation and creek and river systems common for this country type. These characteristics are also likely to explain the reduced mustering efficiency of Northern Forest, compared to other country types. Despite Northern Downs having similar paddock sizes, large areas of rolling grassland plains are present within this region increasing visibility and ease of mustering.

The proportion of properties that indicated that the sale of bullocks was a major source of income was greatest in the Southern and Central Forest and tended to reflect the expected annual growth of yearling cattle. The annual growth was low in the Northern Forest with more than 50kg less annual growth expected for yearling cattle compared to other country types while strong demand for store cattle due to the live export market which explains the least number of properties identifying the sale of bullocks as a main income source within the Northern Forest and is consistent with the profitability of growing steers dependent annual growth and relative prices of store cattle (Sullivan 1992).

In the seasonally dry tropics under nutrition during the dry season is a major constraint for animal production where cattle usually either maintain or lose weight and later regain it during the wet season when pasture quality significantly improves (Dixon *et al.* 2011b). In addition, large areas of northern Australia have been shown to be either marginally or acutely P deficient and the provision of P supplements during the wet season is recommended to increase animal production (Hendrickson *et al.* 1994). During the dry season P is the generally the third most limiting nutrient after energy and protein however, during the wet season the increases in DMD and protein of pastures is greater than that for P which is consistent with the findings of the present study where marginal differences in DMD and protein were observed between country type however, there were vast differences in median values for FP:ME ratios across the wet season which may partly explain differences in expected annual growth rates.

The routine provision of supplemental P during the wet season to breeding females was highest in the Northern Forest and relatively similar across other country types. The ratio of FP:ME in the diet is considered to be a useful indicator of the risk of P deficiency adversely affecting animal performance with the median wet season FP:ME ratio lowest in the Northern Forest and less than suggested threshold value of 390-460 mg P/MJME for a 400 kg lactating cow (Jackson 2012), supporting the high use of supplemental P during the wet season within this country type. However, in the Northern Downs only 31% of producers reported that routine supplemental P was provided whilst approximately half of FP:ME ratios observed within the Northern Downs were less than the estimated threshold values for lactating cows. This suggests that potential production gains in some years may be able achieved by the provision of supplemental P to lactating cows within the Northern Downs.

The median values for dietary crude protein content of the pasture during the dry season were approaching maintenance for all country types as responses to the provision of supplementary protein are likely when pastures are lower than between 60 g CP/kg (6%) (Minson 1990) to 1.3 g faecal N/kg (8%) (Winks *et al.* 1979). However, the lowest protein content observed during the dry season was in the Northern Forest and is consistent with the largest percentage of herd owners/managers routinely providing dry season supplements in the Northern Forest, which is similar to findings reported by O'Rourke *et al.* (1992) and Bortolussi *et al.* (2005a). The lowest routine use of dry season supplements was within the Northern Downs and had the greatest variability in dry season protein levels. High protein values during the dry season within the Northern Downs can potentially be explained by swamp areas of high pastoral value known to be present in the region. In addition, the management practice of segregating breeding cattle based on either lactation status or predicted window of calving was highest for Northern Downs, which is often associated with either the culling of predicted out of season calving cows or the strategic supplementation of only dry season lactating cows and potentially explains the reduced proportion of properties routinely providing dry season supplementation for this country type. The median values for dietary crude protein content of the pasture during the wet season were likely to be above maintenance in all country types and approximately comparable. However, some values observed within the Northern Forest during the wet season were indicative of a likely response to supplemental protein which is consistent with previous reports (McCosker *et al.* 1991).

The DMD of the pasture is an indicator of the amount of the metabolisable energy available the animal. The mean DMD of dry season pastures was similar across country types and was thought likely to support maintenance requirements of non-lactating breeding cattle. However, high maximum mean dry season DMD values were recorded in both the Southern Forest and Northern Downs. The mean wet season DMD was less in the Northern Forest relative to other country types, with the mean wet season DMD recorded across the study period being relatively consistent across the Southern and Central Forest and Northern Downs.

Overall, the bull percentages were highest in the Northern Forest and lowest in the Southern Forest. The bull percentages observed in the current study were generally lower than that reported by

O'Rourke *et al.* (1992) and may be due to the adoption of research findings that recommended their reduction such as Fordyce *et al.* (2002). However, the current bull percentages used still remain higher than the 2.5% recommended as being adequate under extensively managed environments, assuming all bulls mated were reproductively sound. These findings suggest that scope still remains for further economising of bull purchases in the survey population if supported by annual breeding soundness evaluations being performed and only sound bulls mated.

With the exception of the Northern Forest, more than half of respondents within each of the other country types mated bulls for less than 7 months. The frequency of respondents mating bulls for shorter periods was greatest within the Southern Forest. Of those properties that mated bulls for longer than 7 months, 60% within the Northern Downs supported this management practice by segregating heifers and cows either on lactation status at their first annual muster or expected periods of calving. However, within the Northern Forest, only 5% of producers who mated for greater than 7 months segregated heifers and cows.

On average, the typical age at which progeny were weaned was relatively uniform across country types. However, progeny were reported as being weaned at younger ages within the Northern Forest than other country types. Also, for those properties that were culling cows based on age, the mean culling age was uniform across country types. However, the proportion of study participants culling based on age varied between country types, with the lowest proportion observed within the Northern Forest and highest in the Southern Forest. It is speculated that the reduced frequency of producers practicing culling based on age within the Northern Forest is due to a combination of factors such as a high proportion of producers in this country type wishing to significantly increase herd size and cow mortality rates estimated to range between 3-11% in this region (Henderson *et al.* 2013)..

Generally, the proportion of properties vaccinating breeding cattle to control infectious causes of reproductive loss was low. A third of properties were not vaccinating cows and heifers for botulism within the Northern Downs and Forest despite widespread evidence of botulism and suggests that a number of properties within these country types are at significant risk of incurring some mortality as deaths from botulism outbreaks generally occur in unvaccinated herds (Tammemagi *et al.* 1967) that are subjected to periods of protein and phosphorus deficiency. The most common management practice to control campylobacterosis is the vaccination of bulls, however, in areas of low bull control, higher pregnancy percentages in vaccinated heifer cohorts have previously been demonstrated (Schatz *et al.* 2006). Consistently, low levels of vaccination in heifers and cows and moderate levels of vaccination in bulls were observed across all country types with the exception of Southern Forest. Within the Southern Forest, the management practice of vaccinating for campylobacterosis was low in all classes of cattle. This suggests that infertility and abortion resulting in from *Campylobacter fetus* var. *venerealis* infection is potentially negatively impacting reproductive performance within Southern Forest and requires extension activities conducted within this area to specifically be tailored to mitigate this potential area of lost performance.

It is acknowledged that participating properties of the Cash Cow project were identified using a non-random process aimed at enrolling representative herds where good cooperation was highly-likely to be achieved. The cooperating herds are considered to be broadly representative of north Australian beef breeding enterprises in terms of geography, size and ownership however, the results may reflect those for herds managed by more motivated owners/managers that were seeking to improve their understanding of herd performance and factors affecting it than truly typical herds.

4.6 Conclusions

This study successfully described the management practices and some nutritional and environmental parameters of participating properties of the Cash Cow project. There were large variations in the size of breeding herds and properties, and their degree of development, within and between country types. There were large differences between ownership between country type with more private ownership in the Southern Forest while in the more extensive parts of Northern Australia a higher degree of corporate ownership. Ownership and duration of property management appeared to be associated with managers likely to have been managing the property for <10 years unless they were an owner of the property.

A high interest to increase cow numbers by more than 10% was evident for the Northern Forest and provided cow mortality rates were being constrained many properties were actively increasing cow numbers with the culling females on the basis of age less frequent. If current stocking rates are aligned to safe carrying capacity estimates investment in additional watering points could support this increase in some instances with less than 15% of paddock areas within 2.5 km from water for some paddocks.

The expected annual growth of yearling cattle estimated by herd managers was more than 50 kg lower in the Northern Forest, compared to other country types, which potentially explained the lower proportion of properties identifying the sale of bullocks as a major source of income.

The nutritional information summarised in this study highlighted that pasture quality during the dry season was likely to be approaching maintenance of cows for approximately 50% of properties in each country type and that responses to rumen degradable protein were also likely in 50% of properties. The proportion of properties routinely providing dry season supplement was highest in the Northern Forest. However, surprisingly low use of dry season supplement was observed for the Northern Downs and was considered to be explained by the higher proportion of properties within this country type segregating cows based on lactation status and pregnancy which generally is accompanied by strategic supplementation practices or culling of out-of-season calving cows.

Vast differences between country type for the amount of available P during the wet season, as indicated by FP:ME, were observed and suggested that dietary P was likely to limit animal production in both Northern Downs and Forest country types if supplemental P was not provided.

Properties within the Northern Downs and Forest generally tended to mate bulls at higher bull:female ratios and for longer periods. These findings highlight the potential for significant reductions in cost per calf produced if producers use BBSE to select replacement bulls and support annual culling decisions collectively enabling producers to use bull to female rations of 1:50 to 1:70 compared to 1:30 The use of best practice processes for the selection of replacement bulls and management of herd bulls was lowest within the Northern Forest and highest within the Central Forest. Across all study participants there was moderate use of best practice processes with respect to bull selection and management.

Despite wide evidence of botulism within the Northern Downs and Forest, approximately one third of properties were not vaccinating cows and heifers for botulism suggesting that a number of properties within these country types are at significant risk of incurring some mortality due to botulism infection. With the exception of Southern Forest, vaccination against campylobacterosis was largely directed towards bulls and little vaccination of heifers and cows. However, within the Southern Forest, the percentage of properties vaccinating against campylobacterosis was low and considered likely to be potentially negatively impacting reproductive performance. It is recommended that activities designed to increase herd manager awareness of potential losses in reproductive performance and production due to infectious diseases such as botulism and campylobacterosis.

4.7 Contributions by others to the chapter

Mr McCosker was responsible for the management of the data across all country types and capturing the data within the country type of Northern Forrest. Mr Smith with the assistance of Mr McCosker was responsible for collating the NIRS and mapping data across all country types. Mr McCosker, under the oversight of Professor O'Rourke, led the analysis and interpretation of the data and was responsible for the writing of the chapter. Professor McGowan led the trial design in conjunction with Professor O'Rourke. Professor McGowan, Dr. Fordyce, Professor O'Rourke, and Mr Smith have also had a substantial intellectual contribution to the interpretation of the data.

Chapter 5 Reproductive performance in a selected population of beef breeding herds in northern Australia.

5.1 Abstract

An observational population-based epidemiological study conducted between 2007 and 2011 involving 78 north Australian commercial beef breeding herds where in excess of 56,000 cattle were concurrently monitored. The observed reproductive performance was described using data drawn from the biannual assessment of cow attributes including pregnancy and lactation status. Both novel and well established measures of reproductive performance were used to describe monitored performance within four broad country types and included: percentage of cows pregnant within 4 months of calving while lactating, percentage of cows pregnant within an approximate 12 month reproductive cycle (annual pregnancy), foetal/calf loss between confirmed pregnancy and weaning, percentage of cows contributing a calf at weaning and percentage of non-pregnant cows retained for rebreeding.

The results from this study are unique as for the first time median (‘typical’) and lower boundary of the top 25% (‘achievable’) levels of monitored performance attained by commercial beef producers have been presented in contrast to current literature which are largely associated with summaries of perceived estimates made by herd managers captured by surveys. The results from this study suggest that 66 calves weaned annually per 100 cows mated is a more appropriate target level of performance for the Northern Forest while the production objective of 75-80 calves weaned annually per 100 cows is generally applicable in other country types. There was clear difference in apparent levels of performance within the Northern Forest with, in absolute terms, 15-20% fewer surviving mated cows contributing a calf at weaning in an annual production year and ~4% higher pregnant cow missing rates, compared to other country type and was considered to explain the ~20% higher retention of non-pregnant cows for rebreeding.

There was substantial variation between herds, both between and within country type with 20-30 percentage point variation in reproductive rates and 5-15 percentage point variation in foetal/calf loss for half the herds in all regions, suggesting that if associated causes of the variation are defined and controllable, substantial opportunities appear to exist to increase the proportion of females weaning a calf annually.

5.2 Introduction

Beef cattle production is the primary form of commercial land use in northern Australia. Sixty percent of the national herd is located within north Australian and represents 9000 beef producing properties (Martin *et al.* 2013). Breeding is a major production activity for north Australian beef cattle properties (Bortolussi *et al.* 2005b). The findings of a recent study suggest that the majority of northern beef producers are not generating profits sufficient to fund current and future liabilities and suggested that improvement in reproductive rates was necessary (McLean *et al.* 2013).

Despite the considerable improvement in the knowledge of physiological processes and management of breeding cattle, continuing problems of low reproductive performance are still evident in recent study data and completed reviews (Burns *et al.* 2010; McLean *et al.* 2013) representing northern Australia. Rigorous estimates of the actual and achievable reproductive performance levels of northern Australia is paramount to facilitate herd managers being able to establish objective performance targets for individual herds and to also guide industry research and extension activities.

Historically, there has been no population-based studies of the reproductive performance of commercial herds in northern Australia. Thus, performance levels estimated in the literature are mostly based on data derived using surveys (Bortolussi *et al.* 2005a) or are based on the performance of cattle on research farms or those involved in specific research projects (Burns *et al.* 2010). From the data published between 1990-2010 and using the 75th or 25th percentile as the achievable level, annual pregnancy percentages of 87%, 54% and 90% for heifers, first-lactation cows and mature cows, respectively and losses between confirmed pregnancy and weaning of 12% and 8% for first-lactation and mature cows, respectively are potentially achievable levels of performance for beef herds across northern Australia (Table 5-1).

Table 5-1. Distribution of published reproductive rates by class of management group from 1990 onwards for beef herds located across northern Australia (Hasker 2000; Schatz and Hearnden 2008; Burns *et al.* 2010)

Animal class	Herds	Percentile 25th	50th (median)	75th
		Pregnant (annual)		
Heifer	16	74%	84%	87%
First-lactation	16	6%	17%	54%
Mature/Mixed*	13	78%	81%	90%
		Confirmed pregnancy to weaning loss		
First-lactation	15	12%	21%	32%
Mature/Mixed*	12	8%	14%	20%

* Female management groups of mixed cow age groups or groups of cows likely to have previously contributed two year groups of calves (approx. ≥4.5 years).

The main objective of the present study was to describe the variation in reproductive performance of commercial beef herds across northern Australia, and estimate achievable levels. For the purposes of this paper, the achievable level of performance is defined as the lower threshold value of the top 25% of cohorts.

5.3 *Materials and methods*

A more comprehensive description of the methodology used in the present study is provided by McGowan *et al.* (2014). The study was conducted between 2007 and 2011.

5.3.1 *Ethical clearance*

Ethical clearance (AEC approval number SVS/756/08/MLA) was obtained from the University Animal Ethics Committee (Production and Companion Animal), The University of Queensland.

5.3.2 *Study herds and location*

A prospective population-based epidemiological study was conducted in commercial beef breeding herds in northern Australia where approximately 56,000 cows in 165 groups located on 78 different commercial beef properties (farms) within major beef breeding regions of Queensland, the Northern Territory and Western Australia were monitored (Figure 4-1). Herds were selected by project regional coordinators or collaborating veterinarians as meeting the following criteria: 1) Only herd managers who were keen to participate and support the project and thought likely to maintain accurate records were included. 2) Properties were selected that were considered to be typical in their region for their property size and herd management. 3) Herd managers were prepared to maintain the enrolled management groups on their property, with the exception of females culled as per normal property breeding herd management policy, for the duration of the study. 4) All enrolled females were individually electronically identified for the duration of the study. 5) The herd manager was prepared to attend a one-day training workshop in assessing standing pasture biomass and land condition. 6) Properties had access to reasonable working-condition cattle handling facilities and, herd managers were prepared to ensure that all enrolled management groups were mustered a minimum of twice a year, once at the time of branding and/or first annual weaning muster and then again for pregnancy diagnosis either at least six weeks after the bulls were withdrawn or in continuously mated herds at the time of the second (final) annual weaning muster which is usually conducted during the mid-dry season (August-October). 7) All pregnancy diagnosis and foetal aging of enrolled management groups was conducted by accredited cattle veterinarians or beef production research officers 8) Properties had access to weighing facilities and at a minimum, were prepared to record the individual live weight and associated information for weaners from each enrolled herd at each weaning.

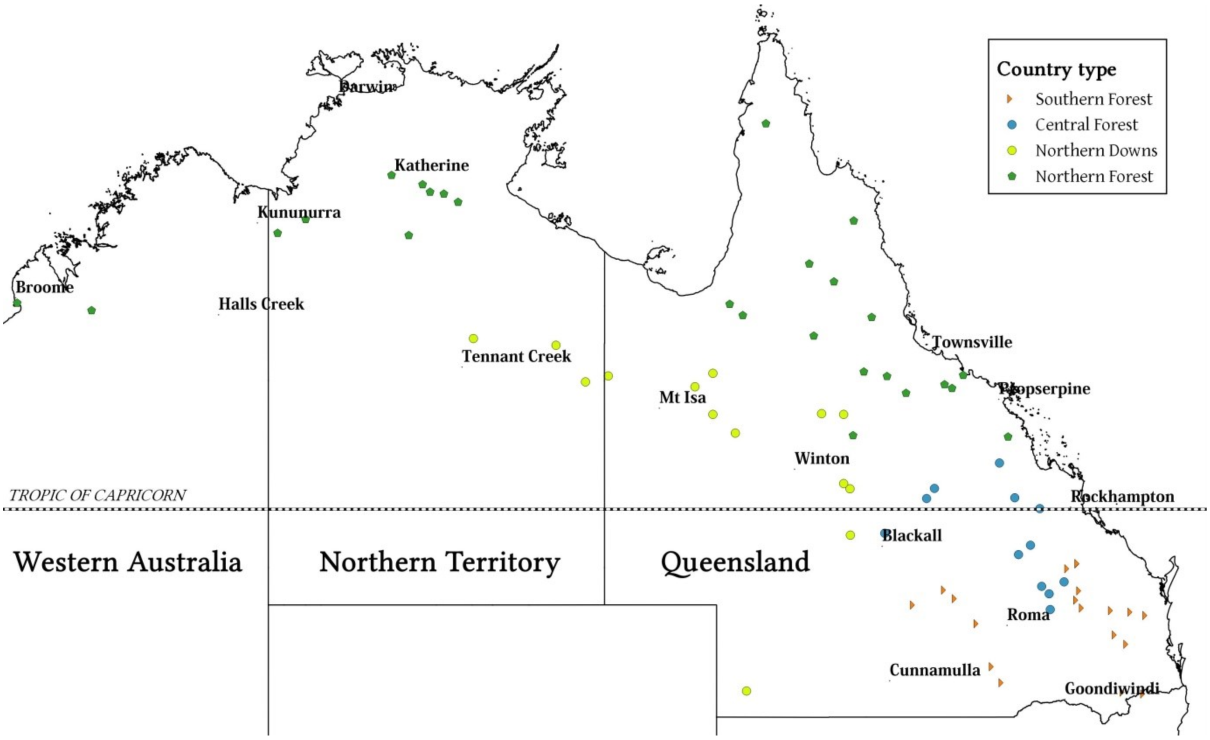

Figure 5-1. Location of cooperating herds by country type.

Cooperating properties were progressively enrolled over 2 years. Initially, a pilot study involving 13 properties, each enrolling a management group of selected maiden heifers, was undertaken during 2007-2008 to inform the management and design of the larger observational study that was conducted during 2009-2011. Each cooperating property typically enrolled two cohorts of females, a management group of heifers that were planned to be exposed to bulls for the first time and a management group of mature cows. All females were enrolled in groups of at least 100 females. In management groups that were larger than 500 females, a representative subset of 300 females was enrolled.

5.3.3 Regionalisation of properties – country type

Properties were assigned to one of four broad country types following a subjective assessment of the production potential of the grazing land and cross-referencing with pasture and vegetation descriptions reported by the herd managers. Property managers were asked to provide an estimate of the mean annual growth of yearling steers (AGYS) expected where the cattle enrolled in the study were grazed. Properties with forested land-types with fertile soils in the central and south-east regions of Queensland were differentiated by being outside

(Southern Forest; median AGYS 200kg) and within (Central Forest; median AGYS 180kg) the northern Brigalow Forest. In the northern areas of Queensland, Northern Territory and Western Australia, properties with land types that were predominantly large treeless black soils plains (Northern Downs; median AGYS 170kg) were segregated from those with forested land-types and low fertility soils (Northern Forest; median AGYS 100kg).

5.3.4 Monitoring the reproductive performance of study herds

Heifers and cows were individually identified using National Livestock Identification System (NLIS, www.nlis.mla.com.au) compliant radio frequency identification device (RFID) ear tags. RFID tags were replaced if the tag was missing or was present but could not be read. In the event of a RFID tag being replaced, data linkages to previous performance records were often able to be established as study animals were individually identifiable by a visual identification tag.

Individual animal data were captured at two annual musters, a main branding or weaning muster and a pregnancy diagnosis (PD) muster. At a heifer or cow's enrolment, information on property, class and year brand were captured. At each muster, management group, lactation status and an animal's fate within a herd were recorded. Foetal age was recorded for all cows diagnosed pregnant at the PD muster.

5.3.5 Cow-age class.

A heifer cohort was defined as a group of female cattle up to the time the majority of the group had their first calf, after which the cohort is classed as first-lactation cows. First-lactation cows became second-lactation cows when the majority of the cohort weaned their first calf, and were classed as mature a year later. Mature cows were defined as less than 9 years of age (determined by year brand), after which they were defined as aged cows.

5.3.6 Derivation of measures of reproductive performance

Performance measures have been summarised separately for each cow-age class. All measures of performance were derived using aggregated individual animal data, which summarised their performance throughout an annual production cycle (period between pregnancy diagnosis muster in one year to the pregnancy diagnosis muster the following year); those measures that do not relate to this period have been defined specifically. It is recognised that an annual production cycle was not exactly equal to one year on all occasions but this period fits in well with the annual management for most northern beef properties. In most instances, performances of cohorts were derived by aggregating individual performance data by cow-age class and year for each property. Although, for those herds that were managed as distinct management groups within a property with no interchanging of animals between management groups these measures have been derived by aggregating individual animal performance data by cow-age class and year for each management group rather than for each study property.

Pregnant within four months of calving in lactating cows (P4M)

P4M was defined as cows mated that became pregnant within four months of calving whilst lactating. The date of calving and the date of conception following calving, which were then used to generate P4M, were estimated based on results of foetal ageing following manual rectal palpation of the reproductive tract. The predicted month of calving was calculated using estimated foetal age at the date of the pregnancy diagnosis muster and projected forward using an assumed gestation length of 287 days. Only those cows that successfully reared their confirmed pregnancy in the previous annual production cycle were eligible for this outcome variable to be generated.

Annual Pregnancy

Annual pregnancy was defined as the cumulative percentage of cows mated that became pregnant in the year after September 1 as resulting progeny were likely to be considered as being of suitable age for weaning and contribute to the calf-crop in continuously mated herds in the following year.

During data checking procedures, pregnancy status of individual animals was cross-referenced against and corrected for subsequent lactation. On occasion, miss-classified not-pregnant animals were identified, which were retrospectively ascribed as being pregnant.

Remated

Remated rate was defined as the percentage of cows that were mated again after having failed to conceive in the preceeding 12 months.

Foetal/Calf loss

Foetal/Calf loss was defined as the percentage of pregnant cows that failed to rear their pregnancy over an annual production cycle. Females were recorded as having failed to rear their pregnancy if they were recorded as being not lactating ('dry') at the first muster after the expected calving date, provided this muster occurred greater than one month after the expected month of calving, and they were not subsequently recorded as lactating. Females were recorded as successfully rearing a calf if they were diagnosed as being pregnant and were then recorded as 'lactating' after the expected calving date. It should be noted that this measure does not include calf loss between branding and weaning and that those females lost to follow up during an annual production cycle were not eligible for this outcome and therefore, this outcome does not represent foetal/calf losses as a result of cow mortality.

Contributed a weaner

Contributing a weaner was a rate calculated over the entire breeding-to-weaning period that was defined as the percentage of mated cows which produced a live calf at muster at least one month after calving. Females were recorded as having successfully contributing a weaner if they were diagnosed as being pregnant in the previous year and were recorded as 'lactating' at an observation after the expected calving date. Alternatively, females were recorded as having failed to wean a calf if they either failed to become pregnant in the previous year or were recorded as having experienced foetal/calf loss in the current year. It should be noted that those females that were lost to follow up during an annual production cycle were not considered to be eligible for this outcome and therefore, this outcome does not represent cows that have failed to produce a weaned calf as a result of cow mortality. It is also recognised that this measure does not include calf loss between branding and weaning.

Missing pregnant breeding females

Missing pregnant breeding females was defined as the cumulative percentage of diagnosed pregnant cows during a production year that without any record of being culled, did not contribute any further data at any of the subsequent musters. Pregnant cows classified as missing were considered to provide an indirect record of mortality, given that many extensive beef properties are not able to observe cattle in order to accurately determine mortalities. Any animal that was not present at two or more musters and failed to be recorded at any subsequent muster until the end of the project was classified as absent for the earlier musters when it had not been present. This means that only heifers or cows that were enrolled before 2011 were eligible to meet the case definition as they could only be ascribed as being missing after they had missed a minimum of two consecutive mustering events. Missing females were only able to be identified once the study had concluded when all possible observation periods could be reviewed to ensure that animals were not classified as missing and subsequently at a mustering event. Animals that were known to have died were classified as missing from when they were known to have died. An absent animal was therefore any animal that failed to be yarded for an observation period but that was known to be alive because it subsequently turned up at a later mustering period.

This outcome was only generated for those herds that the identified missing heifers and cows were able to be cross-referenced to the NLIS transaction records providing additional assurances that the animals had not been inadvertently sold from the properties. However, it should be noted that pregnant cows missing, is likely to be an over-estimate of mortality as it includes cows that lost their lifetime traceability due to loss of NLIS tag, or were un-reportedly relocated within the property due to misadventure.

5.3.7 Determining typical and achievable levels of performance

For all measures of performance, the minimum, maximum, and 25th, 50th (median) and 75th percentiles were chosen as summary statistics to describe the observed variation in performance and to demarcate useful targets for producers and veterinarians. A commercially achievable level of performance was defined as the lower boundary of the most favoured 25% of observations and is consistent with other recently published studies (McLean *et al.* 2013). For performance measures, such as annual pregnancy, P4M and contributed a weaner the 75th percentile was used. However, for foetal/calf loss and missing pregnant cows the 25th percentile or upper boundary of the lower 25% of values derived was used. The 50th percentile or median value was considered by the authors as a typical level of performance.

5.4 Results

The starting dataset was derived from 56,534 unique animals from 78 herds and contained 113,047 animal production years of data for either annual pregnancy, P4M, retained-open, foetal-calf loss, missing and or contributed a weaner. A mean of 1.95 (95% CI, 1.94-1.97) and 2.02 (95% CI, 2.01-2.03) production years of data was contributed by each individual heifer or cow, respectively, and 2.9 (95% CI, 2.8-3.1) production years of data for herds. The median and interquartile range for number of cows or heifers representing a study herd in a production year was 322 and 223-553, respectively (Table 5-2).

Table 5-2. Descriptive statistics for data contributed by herds within each country type.

Country Type	No of herds	No. of years each herd contributed data	No. of observations per herd per year	No. of unique heifers/ cows per herd
		Mean (95% CI)	Median (IQR)	Median (IQR)
Southern Forest	21	2.9 (2.6-3.2)	254 (171-350)	341 (239-562)
Central Forest	13	3.2 (3.0-3.5)	322 (201-472)	380 (354-707)
Northern Downs	13	3.1 (2.6-3.6)	551 (307-763)	822 (674-1085)
Northern Forest	31	2.7 (2.5-3.0)	329 (254-561)	616 (319-786)

IQR: interquartile range; range from the 25th percentile to the 75th percentile, or middle 50 percent of data.

5.4.1 Reproductive performance

Table 5-3. Distribution of herd reproductive performances observed for each cow-age class by country type. The achievable level of performance has been identified by <u>underscoring</u> of either the 25th or 75th percentile value.

Measure of performance and Cow-age class	Southern Forest						Central Forest						Northern Downs						Northern Forest					
	n	Percentile					n	Percentile					n	Percentile					n	Percentile				
		0	25	50	75	100		0	25	50	75	100		0	25	50	75	100		0	25	50	75	100
Annual pregnancy (%)																								
Heifer	16	40	75	86	<u>92</u>	99	11	43	72	80	<u>87</u>	99	14	40	77	87	<u>94</u>	99	20	9	40	67	<u>81</u>	89
First lactation cows	14	44	68	85	<u>91</u>	97	10	62	75	78	<u>85</u>	91	11	18	46	73	<u>87</u>	94	12	2	21	45	<u>79</u>	97
Mature cows	55	50	77	88	<u>94</u>	100	34	31	79	88	<u>93</u>	98	30	40	74	82	<u>90</u>	97	67	10	57	68	<u>76</u>	95
Aged cows	34	55	77	89	<u>94</u>	100	20	42	84	90	<u>96</u>	100	23	39	70	83	<u>91</u>	98	52	18	55	63	<u>76</u>	93
P4M (%)																								
First lactation cows*	14	10	22	38	<u>80</u>	93	10	13	33	48	<u>68</u>	79	11	0	19	40	<u>63</u>	76	11	0	4	11	<u>20</u>	81
Second lactation cows†	10	44	49	63	<u>81</u>	93	10	50	56	64	<u>74</u>	99	7	50	60	62	<u>67</u>	77	7	0	2	11	<u>49</u>	63
Mature cows	26	11	43	74	<u>90</u>	98	20	10	57	77	<u>84</u>	97	18	21	57	67	<u>76</u>	83	32	3	9	17	<u>35</u>	83
Aged cows	10	50	57	80	<u>91</u>	93	9	31	61	84	<u>90</u>	93	9	59	68	70	<u>74</u>	80	18	3	6	18	<u>24</u>	72
Remated (%)																								
Heifer	16	0	<u>1</u>	7	21	60	11	0	<u>1</u>	2	15	38	14	0	<u>1</u>	9	16	60	19	1	<u>4</u>	23	57	91
First lactation cows	14	0	<u>2</u>	4	10	35	10	0	<u>0</u>	1	19	34	9	0	<u>0</u>	14	22	53	10	2	<u>14</u>	45	75	98
Mature cows	54	0	<u>0</u>	4	13	49	34	0	<u>0</u>	3	8	68	30	0	<u>2</u>	8	17	60	65	1	<u>20</u>	32	41	90
Aged cows	33	0	<u>0</u>	3	12	45	16	0	<u>0</u>	0	3	22	20	0	<u>2</u>	9	14	61	51	0	<u>18</u>	30	43	82
Foetal/Calf Loss (%)																								
Heifer	14	0	<u>4</u>	9	14	27	11	1	<u>4</u>	10	18	41	12	0	<u>7</u>	15	20	26	13	7	<u>11</u>	15	19	31
First lactation cows	10	0	<u>1</u>	5	7	21	9	1	<u>3</u>	7	9	14	8	3	<u>4</u>	5	8	15	4	5	<u>7</u>	10	12	14
Mature cows	29	0	<u>2</u>	5	7	18	20	1	<u>3</u>	6	9	27	19	0	<u>3</u>	8	15	19	37	3	<u>8</u>	12	17	42
Aged cows	9	0	<u>1</u>	3	9	12	9	0	<u>4</u>	5	12	16	9	0	<u>2</u>	3	10	14	25	3	<u>10</u>	14	22	46
Pregnant cows missing (%)																								
First lactation cows*	12	2	<u>3</u>	7	10	25	11	1	<u>3</u>	12	17	19	11	0	<u>4</u>	7	9	28	8	4	<u>6</u>	8	9	18
Mature cows	15	0	<u>3</u>	6	12	22	11	0	<u>1</u>	7	11	14	10	0	<u>5</u>	7	12	27	14	1	<u>5</u>	11	19	27
Aged cows	9	0	<u>8</u>	11	14	22	6	0	<u>5</u>	7	9	12	7	2	<u>3</u>	7	16	28	12	0	<u>6</u>	12	20	30

*Heifers that had successfully reared their first confirmed pregnancy

†First-lactation cows that had successfully reared their second confirmed pregnancy.

Table 5-3. Continued.

Measure of performance and Cow-age class	Southern Forest						Central Forest						Northern Downs						Northern Forest					
	n	Percentile					n	Percentile					n	Percentile					n	Percentile				
		0	25	50	75	100		0	25	50	75	100		0	25	50	75	100		0	25	50	75	100
Contributed a weaner (%)																								
Heifer	14	31	64	76	85	90	10	32	61	70	83	94	11	30	63	77	84	92	15	8	24	56	71	78
First lactation cows*	12	34	58	76	89	96	10	57	67	71	76	87	9	14	47	68	82	88	8	1	14	31	64	83
Mature cows	30	52	67	83	92	99	20	65	70	79	88	99	20	41	61	71	79	92	40	25	51	57	64	91
Aged cows	15	41	68	79	90	98	12	35	68	84	91	100	12	40	65	73	79	89	29	27	43	51	65	79

*Heifers that had successfully reared their first confirmed pregnancy

†First-lactation cows that had successfully reared their second confirmed pregnancy.

Generally, annual pregnancy percentages were lowest for first lactation heifers across country types. Differences between mature and aged cow annual pregnancy percentages appeared to be relatively minor within country types. The distribution of heifer annual pregnancy percentages appeared independent of country type, except in the Northern Forest where rates less than 40% was observed for 25% of cohorts compared to no heifer cohorts in either Central Forest or Northern Downs and 1 (6%) cohort in the Southern Forest. No heifer cohorts in the Northern Forest were observed with annual pregnancy percentages exceeding or equal to 90%. However, 7 (44%), 2 (19%) and 6 (43%) were observed in the Southern Forest, Central Forest and Northern Downs, respectively. The 50th (median) and 75th percentile values for annual pregnancy percentage of 22 yearling mated (mated for the first time in the year which they were weaned) heifer cohorts, representing 20 herds, across the Southern Forest, Central Forest and Northern Downs country types, were 75% and 81%, respectively. One herd in the Northern Forest conducted yearling mating with an annual pregnancy percentage of 32%.

P4M generally was lowest for first-lactation cows within each country type. With the exception of Northern Forest, the 75th percentile value was similar for both first and second lactation cows. However, in the Northern Forest the 75th percentile value of second-lactation cows tended to be greater than the 75th percentile values for all other cow-age classes in the Northern Forest. Differences in the performances of Mature and Aged cows within country types appeared to be minimal with the exception of Northern Forest where P4M was generally slightly lower in aged cows than in mature cows. Two (4%) first-lactation cow cohorts were observed as having 0% P4M with one in each of the Northern Downs (9%) and Northern Forest (9%) country types. In the Northern Forest, 1 (14%) second-lactation cow cohort was also observed with no females successful for P4M. In the Northern Forest 9 (82%) first-lactation cow cohorts were observed with P4M <25% versus 5 (36%), 2 (20%) and 3 (27%) in the Southern Forest, Central Forest and Northern Downs, respectively. Across the country types of Southern and Central Forest, and Northern Downs, approximately, 5% (5/92) of either mature or aged cow cohorts were observed with P4M outcomes <25% versus 64% (32/50) of either mature or aged cow cohorts within the Northern Forest.

Generally, the percentage of non-pregnant females retained for subsequent breeding was higher in the Northern Forest than for other country types. No heifers were retained for subsequent rebreeding in 3 (19%), 1 (9%) and 3 (21%) cohorts in the Southern Forest, Central Forest and Northern Downs, respectively. All heifer, first-lactation and mature cow cohorts within the Northern Forest retained some non-pregnant females for subsequent rebreeding. Approximately, 30% of mature cow cohorts in Southern and Central Forest did not retain non-pregnant cows for breeding while 5 (17%) mature age cow cohorts within Northern Downs retained no non-pregnant cattle. In the Southern Forest, Central Forest, Northern Downs and Northern Forest no non-pregnant females were retained for subsequent rebreeding in 11 (33%), 8 (50%), 4 (20%) and 1 (2%) of aged cow cohorts, respectively.

Foetal/calf loss was generally higher for Heifers than for other categories of cow-age class. Generally, there was moderate variation within cow-age class between country types for foetal/calf loss. However, the Northern Forest tended to be observed with more extreme values being observed. Nine (4%) instances of foetal/calf losses exceeding 30% were observed across all analysis groups in which 8 (89%) were observed within the Northern Forest. Across all country types, the median value for foetal/calf loss in first-lactation cow cohorts was estimated as 15%. In the Northern Forest, 7 (54%) of first-lactation cow cohorts achieved this value versus, 12 (86%), 8 (73%) and 6 (50%) in the Southern Forest, Central Forest and Northern Downs, respectively. Across all country types, 5 (10%) first-lactation cow cohorts exceeded 25% foetal calf loss rates; with one cohort in each the Southern Forest (7%), Central Forest (9%) and Northern Downs (8%), and 2 (15%) in the Northern Forest. Achievable foetal/calf loss of <5% was estimated for cows in the Southern Forest, Central Forest and Northern Downs, but <10% in the Northern Forest. However, foetal/calf loss exceeded 4%, 5%, 7% and 13% in more than half of either mature or aged cows cohorts in the Southern Forest, Central Forest, Northern Downs and Northern Forest, respectively.

Missing second-lactation pregnant cows could not be accurately estimated due to an insufficient number of cow groups being observed within each country type. Excluding Northern Forest cattle, the estimated median value of pregnant second-lactation cows missing was outside the 1-3% range in 3 (33%) observed cohorts. Though the variability in pregnant females missing across cow-age class and country types was large and was generally slightly higher in the Northern Forest compared with other country types, the 25th percentile value (achievable) was relatively consistent across country type within cow-age classes and between cow-age classes within country type. The derived percent foetal/calf loss does not represent losses as a result of cow mortality.

The variation in weaning rates within cow-age class and country type was very large and appeared to be greater for the Northern Forest. Generally, cohorts of females within the Southern Forest tended to have higher weaning rates than for other country types. The 75th percentile value (achievable) for heifers within either the Southern and Central Forest and Northern Downs was approximately 80%, but 70% for the Northern Forest. No heifer cohorts within the Northern Forest achieved a weaning rate of 80%. Differences in weaning rates between Mature and Aged cows within country types were low.

5.5 Discussion

The data from this study provides for the first time median ('typical') and lower boundary of the top 25% ('achievable') levels of observed performance attained by commercial beef producers within four broad country types. These benchmark levels of performance could potentially provide beef producers the basis of a systematic framework to monitor and compare actual levels of reproductive performance which in turn is likely to promote the uptake of reproductive advice and extension programmes by key management decision makers of herds (Brownlie *et al.* 2011).

There was substantial variation between herds, both between and within country type with 20-30 percentage point variation in reproductive rates and 5-15 percentage point variation in foetal/calf loss for half the herds in all regions, suggesting that if associated causes of the variation are defined, understood and controllable opportunity exists to improve reproductive performance. It is acknowledged however, that some biophysical differences within country type are still likely and not all properties residing within country type will have equal opportunity for improvement and any remedial management interventions to improve herd reproductive performance should be supported by whole of business analyses.

With the exception of the Northern Forest, differences between country types were moderately small. However, the monitored performance within the Northern Forest was lower than that previously considered attainable with 15-20%, in absolute terms, fewer surviving mated cows contributing a weaner in an annual production year, compared to other country types. An achievable level of performance for cows contributing a weaner in the Northern Forest was less than two calves from three annual production cycles while a typical level of performance in this country type was approximately one calf every two production years. This finding challenges the recommendation that a suitable level of performance for northern Australia beef herds is 80 calves weaned annually per 100 cows mated (Hasker 2000) and highlights the value of demonstrating what is achievable under commercial, rather than controlled-research, management. The results from this study suggest that 66 calves weaned annually per 100 cows mated is a more appropriate target level of performance for the Northern Forest. However, for all remaining country types, a production objective of 80% weaning rate is generally applicable with all top performing 25% of age-class cohorts achieving weaning rates of ≥75% in the Southern Forest, Central Forest or Northern Downs.

The finding that cows contributing a weaner was lowest in first-lactation cows is consistent with the partitioning of energy towards growth as well as reproduction and is well documented in the literature (Entwistle 1983; Teleni *et al.* 1988; Schatz and Hearnden 2008; Burns *et al.* 2010). This biological mechanism also potentially explains the heightened difference between typical levels of performance for first-lactation and older cows in the Northern Forest compared to other country types as nutritional challenges are likely to be greater in the Northern Forest when compared to other country types. However, it is interesting to note, that the relative reduction in achievable levels of performance for first-lactation cows, compared to mature cows was not evident and potentially suggests that when first-lactation cows in the Northern Forest are managed according to their nutritional requirements their performance is similar to that of mature cows.

A unique feature of this study is that a novel measure of reproductive performance pregnancy within four months of calving whilst lactating (P4M), representing the proportion of cows in a herd that potentially wean a calf in consecutive years, was established and used to describe monitored performance. Determined levels of performance for P4M within cow-age class were vastly different for Northern Forest with observed values 20-50 percentage points lower when compared to other country types. Eighty-two percent of first-lactation cow cohorts within the Northern Forest were determined to have P4M values <25%, compared to <36% of first-lactation cow cohorts in other country types. These results suggest that the environmental stressors within the Northern Forest are too great to support females weaning three calves in their first three mating opportunities unless external inputs are provided in addition to those that are routinely available. These findings also suggest that while improvements in herd profitability could clearly be made with improvements in herd reproductive performance the costs associated with improving reproductive performance may outweigh returns and therefore, low cost strategies to improve herd productivity need to be explored further.

Annual pregnancy percentages observed in this study were comparable to those previously reported (Schatz and Hearnden 2008; Burns *et al.* 2010). They were lowest in first-lactation cow cohorts especially in the Northern Forest where 34 percentage point fewer pregnancies occurred compared to mature cows which contrasts to a 3-11 percentage point difference in other country types, which is consistent with other literature (Entwistle 1983). When cow mortality and foetal/calf loss are minimal, annual pregnancy percentages of 75% or greater has been previously stated as being an adequate level of performance to produce enough pregnant replacement breeding females to maintain a static herd while culling all non-pregnant females (Schatz and Hearnden 2008). The findings in this study suggest that with the exception of the Northern Forest, the majority of herds in other country types could potentially maintain a static herd while culling all non-pregnant females and increase genetic gains for lifetime performance. However, in the Northern Forest, only ~25% of cow cohorts achieved annual pregnancy percentages >75% and there was large disagreement between annual pregnancy values and P4M, which is likely to indicate a large proportion of pregnancies occurring in response to weaning and further supports the recommendation of not culling all non-pregnant cows within the Northern Forest.

Although non-pregnant heifers within the Northern Forest were less likely to be remated relative to other cow-age class cohorts, more than 25% of non-pregnant heifers were remated in more than half of the monitored herds. This finding highlights a need for further extension activities by advisors and government agencies to increase adoption of selecting only pregnant heifers to increase genetic selection pressure for earlier age at puberty and lifetime performance (Johnston *et al.* 2013). The heightened proportion of non-pregnant mature and aged cows remated in the Northern Forest compared to other country types is potentially explained by 15-20 percentage point lower weaning rates and ~4 percentage point higher pregnant cow missing rates. When adjusted for pregnant cows missing, only 51 calves per 100 mature cows mated was estimated as a typical level of performance within the Northern Forest and is below the performance level required to maintain cow herd size unless some non-pregnant cows are retained for remating.

Irrespective of cow-age class cohort, significant levels of foetal/calf loss (5-15%) were observed across all country types with levels exceeding 20% not uncommon and exceeding 40% in some instances. However, with the exception of Northern Forest, an achievable level of performance for all other country types was approximately 5% foetal/calf loss. Holroyd (1987) suggested an acceptable level of foetal and calf loss between confirmed pregnancy and weaning of 12% for a well-managed herd in the northern forest, which is comparable to the 10% suggested by the present study. Foetal/calf loss in cows tended to be 3-11 percentage points higher in the Northern Forest relative to the other country types. Typical levels of foetal/calf loss was 1-12 percentage points higher in heifers when compared to older cow-age class cohorts which is consistent with previous findings (Reynolds *et al.* 1980; Entwistle 1983) The mechanism that cow-age class affects foetal and calf losses is uncertain however, it is speculated that due to learnt maternal instincts the prevalence of mismothering as a cause of foetal/calf loss is considered to reduce with parity (Schatz 2011; Bunter *et al.* 2013). It should also be noted that measures of foetal/calf loss in the present study do not include losses due to cow mortality. Mortality risk for cows has been shown to increase during the late dry and early wet season periods and therefore, typically coincides with the period after conception and prior to weaning (O'Rourke 1994). Therefore, based on the median values for pregnant females missing, the reported values for foetal/calf loss are possibly a further 4 percentage points higher, in the Northern Forest than the other country types.

Although pregnant cow missing rates of ≤5% appeared achievable in all country types, up to 20% were observed for all country types and is potentially explained by seasonal variation and climatic events such as flooding and prolonged periods of below-average rainfall which were observed during the study. However, this finding also identifies a need for further RD&E, as cow mortality has long been recognised as having an important impact on profitability and even viability of beef breeding enterprises in northern Australia (O'Rourke 1994; McCosker *et al.* 2010b) and there appears to be difference in perceived cow mortality rates and those occurring in reality. Producers in the Northern Territory recently estimated breeder mortality rates much lower than that estimated in this study with 4.2% average breeder mortality in Katherine/Top End and 3.0% in Barkly region (Cowley *et al.* 2014) while the indicative pregnant cows missing in the current study were 8-12% in the Northern Forest and 7% in the Northern Downs. Furthermore, the estimates of pregnant cows missing in the present study are comparable to cow mortality rates described in a recent study involving north Australian commercial beef herds which reported unadjusted cow mortality rates ranging between 9-17% for areas within the Northern Forest and 4% in an area of the Northern Downs (Henderson *et al.* 2013).

The data presented is unique as it involved the simultaneous monitoring of a selected population of commercially managed beef females in the major beef cattle breeding region of Australia. However, it is acknowledged that bias may have been created by using herds where managers were prepared to conduct an annual pregnancy diagnosis on all enrolled females, a management practice that is not routine in many areas of northern Australia. Despite appropriate diligence being placed on data collection, incomplete data because of non-ideal cattle control may have created further error. Overall, the error may have been in favour of slightly higher performance when compared to fully-representative herds.

5.6 Conclusions

This study defined typical and achievable levels of reproductive performance of commercial beef herds located across northern Australia. There was marked variation in the reproductive performance of breeding herds both within and between country types with reproductive performance for Northern Forest markedly different to other country types. The prevalence of foetal/calf loss was high, as was the proportion of non-pregnant heifers and non-pregnant cows remated annually. Substantial opportunities appear to exist to increase the proportion of females weaning a calf annually.

5.7 Contributions by others to the chapter

Mr McCosker was responsible for the management of the data across all country types and capturing the data within the country type of Northern Forrest. Mr McCosker, under the oversight of Professor O'Rourke, led the analysis and interpretation of the data and was responsible for the submission and writing of the chapter. Professor McGowan led the trial design. Professor McGowan, Dr. Fordyce, and Professor O'Rourke also had intellectual contributions to the interpretation of the data and writing of the chapter.

Chapter 6 Descriptive analysis of major factors affecting reproductive performance of commercial beef herds in northern Australia.

6.1 Abstract.

A prospective epidemiological study was conducted in a selected population of commercial beef breeding herds in northern Australia to determine and quantify the major associations between herd management, nutritional and environmental factors and individual cow attributes and measures of reproductive performance. Using four major country types based on the reported production potential of the grazing land, this paper presents descriptive summaries of the study population for the risk factors identified as major determinants of one or more measures of reproductive performance.

Pasture quality on properties within the Southern Forest was generally adequate during the wet season (Nov-Apr) however, on one third of enrolled properties within the Northern Forest and Northern Downs pasture quality was considered inadequate during the wet season. Additionally, the occurrence of P deficiency likely to affect reproductive performance was greater in the Northern Forest than other country types.

Although in the present study it was generally found that body condition score (BCS) at the time of pregnancy diagnosis (approximately 5 months prior to expected time of calving) was lower for first-lactation cows than for lactating multiparous cows, in the Northern Forest the BCS of parity 1 and multiparous cows was similar. Overall, 14-23% more, in absolute terms, of lactating multiparous cows gained condition between pregnancy diagnosis and the subsequent branding/weaning muster than compared to first-lactation cows.

A high proportion of enrolled properties considered wild dogs were adversely affecting herd performance and had a policy to actively control wild dogs. Only approximately 20% of enrolled properties in the Southern Forest and ≤10% in other country types considered wild dogs were not adversely affecting herd performance.

6.2 Introduction

There is known large variation in the reproductive performance of north Australian beef cattle herds (O'Rourke *et al.* 1992; Cowley *et al.* 2014). Numerous studies have identified herd, management group and animal-level factors affecting reproductive performance

(Hasker 2000) and many of these were recently comprehensively reviewed (Burns *et al.* 2010).

Poor reproductive performance is often multifactorial and there is increasing emphasis being placed on the understanding of the amount of reduced animal performance that is attributable to each factor affecting reproductive performance. Population-based research is facilitated by the collection of large amounts of data captured using standardised approaches and enables increased understanding of prevalence risk factors occur within a population for different time points and allows the unbiased evaluation of their association with outcome variables. Through the development of computer packages that allow the crush-side capture of individual cattle data at commercial processing rates and electronic identification devices, the generation of datasets that allow the undertaking of such study designs has become logistically feasible in recent years.

A prospective population-based epidemiological study was conducted in commercial north Australian beef breeding herds between 2007 and 2011. The study was conducted to determine and quantify the major associations between herd management, nutritional and environmental factors and individual cow attributes and measures of reproductive performance. The present paper presents descriptive summaries of risk factors identified as major determinants of one or more measures of reproductive performance. The results of multivariate analyses are presented in companion papers; risk factors affecting the occurrence of lactating cows becoming pregnant within four months of calving (P4M) (Chapter 7), cows failing to become pregnant within an approximately 12 month reproductive cycle (Chapter 8), foetal/calf loss (Chapter 9) and pregnant cows subsequently becoming listed as missing (Fordyce *et al.* In press).

6.3 Materials and methods

6.3.1 Data background

A comprehensive description of the methodology to collect and derive data (Chapter 3) and the subsequent analyses to identify the major factors affecting the occurrence of lactating cows becoming pregnant within four months of calving (P4M) (Chapter 7), cows failing to become pregnant within an approximately 12 month reproductive cycle (Chapter 8), foetal/calf loss (Chapter 9) and pregnant cows subsequently becoming listed as missing (Fordyce *et al.* In press) are provided by the listed papers.

Briefly, a large prospective population-based epidemiological study that was conducted between 2007 and 2011; the target population was considered to be the commercial beef breeding herds in northern Australia and involved 78 different commercial beef properties (farms) with approximately, 78,000 cows managed as up to 165 breeding groups contributing explanatory and performance data (Figure 4-1).

The monitoring of animal data was facilitated by the use of electronic performance monitoring systems that recorded data against individual animal identification devices. Performance and explanatory data were recorded twice a year for each heifer or cow enrolled into the project, at the main branding or weaning muster and again at the pregnancy diagnosis (PD) muster. At each muster, body condition, lactation status were assessed and recorded. Foetal ageing was conducted once per year (preferably in September in continuously-mated herds or 6 weeks after the removal of bulls in control-mated herds). The age the foetus was estimated using half monthly increments between 1-5 months, and thereafter foetal age was estimated in one monthly increments.

Environmental factors were largely derived from interpolated data drawn from Bureau of Meteorology databases based on GPS locations of paddocks or homesteads. Nutritional factors were based on faecal Near Infrared Spectroscopy (F.NIRS) and wet chemistry faecal phosphorus (P) analysis (dung samples collected in January, March, May, August & November) and producer pasture assessments.

Putative risk factors were related to one of four levels: property, property-year, animal and animal-year. Animal-year and property-year were defined as the observed performance of an animal or property, respectively for a single year of observation. The classification of continuous variables was determined during the multi-level model-model building process. Wherever possible, continuous variables were categorised using established threshold values. However, in some cases, where these were not found to be discriminatory, cut points were primarily determined by fitting the continuous variable as a main effect for the outcome of interest and evaluating the shape of the residuals plotted against the values of the predictor variable.

Using exploratory multilevel multivariable modelling the impact of 83 candidate risk factors were assessed for three reproductive outcomes (pregnant within 4 months of calving while lactating; non-pregnancy; foetal/calf loss) and pregnant cows subsequently becoming listed as missing. The results of these analyses are presented in companion papers. However, country type, predicted window when a cow calved, body condition score measured at the pregnancy diagnosis muster, change in body condition score between its measurement at pregnancy diagnosis and weaning/branding muster, cow-age class, average FP:ME during the wet season, year of observation, average DMD:CP during the wet season were identified as major factors influencing pregnancy within 4 months of calving while lactating (Chapter 7) .

The major factors identified as influencing the risk of non-pregnancy were pregnancy status and timing in the previous annual production cycle, average dry season DMD of pasture, BCS at the weaning/branding muster, average FP:ME and DMD:CP during the previous wet season, year of observation, cow-age class and country type (Chapter 8).

Determined factors impacting the likelihood of foetal/calf loss between confirmed pregnancy and weaning in the analyses included mustering within a month of calving, mustering efficiency, BCS at pregnancy diagnosis, Cow-age class, lactation status in the previous production cycle, average FP:ME during the wet season, hip height, temperature-humidity index >79 in calving month and country type (Chapter 9).

The determined major predictors associated with incidence of pregnant cows missing were country type, body condition score, minimum available dry season biomass, body condition score measured at the pregnancy diagnosis muster, interval to follow up rain after wet season onset, period of calving (Fordyce *et al.* In press).

6.3.1.1 Property-year level factors

Property-year level factors identified in the multivariate analyses are described in Table 6-1.

Table 6-1. Details of identified major property-year factors

Factor	Detail
Interval to follow up rain after wet season onset	The number of days following the wet season onset (after September 1 and before March 31, date of accumulation of 50 mm of rainfall within ≤14 days) until another major rainfall event (50 mm of rainfall within ≤14 days). Categorised as either ≤30 days or >30 days
Minimum available dry season biomass	The minimum dry season pasture quantity (mean of estimates May 1 to October 31) reported by property owner/manager. Categorised as either <2000 kg/ha or ≥2000kg/ha.
Dry matter digestibility (DMD) during the dry season.	Mean estimated DMD derived from F.NIRS for samples collected during the dry season (May 1 to October 31). DMD categorised as either <55% and ≥55%.
Ratio DMD;CP during the wet season	Mean ratio of estimated DMD to dietary crude protein (CP) derived from F.NIRS for all samples collected during the wet season (November 1 to March 31). DMD:CP categorised as either <1:8 and ≥1:8.
Risk of P deficiency adversely affecting performance FP:ME	Mean ratio of estimated faecal P to calculated metabolisable energy derived from DMD for each sample collected during the wet season (November 1 to March 31). It should be noted that producers were not instructed to remove P supplements from paddocks prior to collecting faecal samples. FP:ME was categorised as either High (<500 mg P/MJ ME) or Low (≥500 mg P/MJ ME) risk.

6.3.1.2 Animal-year level factors

Animal-year level factors identified in the multivariate analyses are described in Table 6-2.

Table 6-2. Details of identified major animal-year factors.

Factor	Detail
Body condition score	Body condition score was assessed and scored on a 1 to 5 scale using 0.5 increments (Hunt 2006). Body condition was categorised as ≤2.0, 2.5, 3.0, 3.5 or ≥4 at the branding or weaning muster and pregnancy diagnosis muster.
Body condition score change between pregnancy diagnosis and weaning/branding	The change in body condition score between the pregnancy diagnosis muster and the next first annual weaning or branding muster was calculated and categorised as either 'lost', 'maintained' or 'gained'.
Annual lactation	The lactation status of the cow was defined as either having being suckled or not suckled during the reproductive cycle (the period between one annual pregnancy diagnosis muster to the next, typically 12 months later). Annual lactation was based on an aggregation of the lactation status records captured during the year.
Expected month of calving	The predicted month of calving was calculated using foetal age at the date of pregnancy diagnosis and projected forward using a gestation length of 287 days and 30.4 days per month (Casas *et al.* 2011). In instances where a foetus had been aged twice, recorded foetal ages between 2-5 months were considered to have a higher degree of accuracy than >5 months. Ages <2 months were considered quite accurate but prevalence of mortality much greater
Reproductive Outcome	This variable included all cows which had a predicted month of calving and lactated, females which lactated but had not been diagnosed pregnant, and females which were diagnosed not pregnant the previous reproductive cycle and did not lactate

Table 6-2. (Continued)

Factor	Detail
Mustered around the time of calving	Based on the expected month of calving and date of muster, females were retrospectively assigned as having been mustered between 1 month prior to and 2 months after a females expected month of calving. Pregnant female were categorised as either having been mustered or not mustered around the time of calving.
The cumulative number of days in the expected month of calving when Temperature Humidity Index (THI) exceeded 79	Using interpolated temperature and humidity data for the GPS location of either a paddock or homestead from the Australian Bureau of Meteorology (BOM) the THI was calculated for each day and aggregated to represent each month. THI was calculated using the equation: *0.8 x Ambient temperature+(((Relative humidity÷100) x (Ambient temperature-14.4))+46.4)* (Hahn *et al.* 2009)

6.3.2 Cow-age class.

Cow class was represented using three levels of cow-age class. A heifer cohort was defined as a group of female cattle up to the time the majority of the group had their first calf, after which the cohort is classed as first-lactation cows. First-lactation cows were defined as cows during the period when the majority of the cohort was experiencing their first lactation. A second-lactation cow cohort was defined as a group of cows between confirmed pregnancies and weaning in the year after the majority of their cohort contributed their first weaned calf. A mature cow cohort was defined as a group of cows that were less than 9 years of age (determined by year brand) and was not eligible to be defined as either heifers or first- or second-lactation cows. An aged cow cohort was defined as a group of cows that were 9 years of age or older.

6.3.3 Hip Height

Hip height was measured by extending a retractable measuring tape downward perpendicular to the ground from a fixed distance above the squeeze chute and recording the distance from the fixed position to the top of the animal's back between the hips (Parish *et al.* 2012). Hip height was measured once for cows, at first pregnancy diagnosis muster, and twice for heifers, at first pregnancy diagnosis muster and at the pregnancy diagnoses muster of the subsequent year. Females were categorised as: Short (<125 cm), Moderate (125 to <140 cm) and Tall (≥140 cm).

6.3.4 Statistical analyses

The main form of summary and data analysis was frequencies by categories and cross-tabulation by country types. Estimates of proportions and confidence limits were produced using the –proportion- command in Stata for Windows (Version 13.1, StataCorp, College Station, TX, USA). The calculated standard errors of prevalence estimates for animal-level risk factors included adjustment for clustering at the property level by specifying the -cluster- option within the –proportion- command in Stata. The limits of confidence intervals were calculated using a logit transform so that the endpoints were within 0 and 1.

6.4 Results

The starting dataset contained 116,192 rows of data with each row generally representing an individual animal throughout a year and was restricted to only those rows of data containing a valid entry for one of the four outcomes: P4M, non-pregnancy, foetal/calf loss and missing pregnant cows. Eleven percent of the data contained valid entries for all four outcome variables and therefore potentially would have contributed to each multivariate analysis. Considering each outcome variable (expressed as a percentage of the total number of rows in the starting dataset), 93%, 54%, 42% and 35% of the data for P4M, non-pregnancy, foetal/calf loss and missing pregnant cows was complete, respectively

Property or herd-level risk factors can be categorised into three types: aggregate, contextual and group or global (Dohoo *et al.* 2009). Two contextual and one aggregate property- or herd-level risk factors were identified as being important determinants of reproductive performance and their occurrence within country types was summarised and is presented in Table 6-3. Property risk factors that related to a particular production year (property-year) were summarised and are presented in Table 6-4.

Table 6-3. Descriptive summary of the frequency of property-level risk factors by country type.

Risk Factor	Southern Forest		Central Forest		Northern Downs		Northern Forest	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Mustering efficiency <90%								
N=	19		15		13		29	
	15.8	(4.6, 42.2)	0.0		0.0		24.1	(11.4, 44.0)
Wild dogs								
N=	19		14		10		29	
Not considered a problem	21.1	(7.3, 47.3)	7.1	(0.7, 44.1)	10.0	(0.9, 57.8)	6.9	(1.6, 25.4)
Considered a problem:								
- intermittent control only	21.1	(7.3, 47.3)	35.7	(13.7, 66.0)	20.0	(3.7, 62.2)	6.9	(1.6, 25.4)
- routine baiting	57.9	(33.5, 78.9)	57.1	(28.4, 81.7)	70.0	(31.0, 92.4)	86.2	(67, 95.1)

CI = confidence interval
*

Descriptive data on the distribution of animal-level risk factors within a production year are presented for Heifers (Table 6-5), First-lactation cows (Table 6-6) and Cows (Table 6-7). Results describing the risk factor body condition score at branding/weaning muster for Heifers is not presented as Heifers were inducted to the study at the pregnancy diagnosis muster after their first mating period. The analyses presented for first-lactation cows relates specifically to those cows that experienced lactation for the first time. Therefore, heifers that either became pregnant but failed to wean their calf or heifers that failed to become pregnant have been omitted from these analyses.

Table 6-4. Prevalence of property-year risk factors across all property-years, and occurrence in at least one year on individual properties. The mean proportion of properties and property-years, represented as a percentage, and the bounds of the 95% confidence interval are presented.

Risk Factor and Country type	Percentage of property-years with factor (%)			Percentage of properties with factor in at least one year (%)		
	N	Mean	95% CI	N	Mean	95% CI
Interval between onset of wet season and follow up rain > 14 days.						
Southern Forest	58	34.5	(25.3, 45.0)	19	84.2	(59.5, 95.1)
Central Forest	42	35.7	(26.5, 46.1)	13	92.3	(58.1, 99.0)
Northern Downs	35	31.4	(20.2, 45.3)	13	61.5	(32.9, 83.9)
Northern Forest	79	15.2	(9.8, 22.8)	28	42.9	(25.7, 62.0)
Minimum dry season biomass <2000 kg/ha						
Southern Forest	59	33.9	(21.6, 48.8)	19	68.4	(44.1, 85.6)
Central Forest	48	35.4	(21.0, 53.0)	15	66.7	(39.3, 86.1)
Northern Downs	41	29.3	(13.3, 52.8)	13	46.2	(21.3, 73.1)
Northern Forest	87	37.9	(28.4, 48.4)	31	74.2	(55.6, 86.8)
Mean dry season DMD ≤55%.						
Southern Forest	59	67.8	(49.4, 82.0)	19	89.5	(64.8, 97.5)
Central Forest	48	68.8	(50.5, 82.6)	15	86.7	(57.6, 96.9)
Northern Downs	41	68.3	(46.7, 84.1)	13	92.3	(58.1, 99.0)
Northern Forest	87	72.4	(58.8, 82.8)	31	87.1	(69.5, 95.2)
Mean wet season DMD:CP ≥8:1						
Southern Forest	33	3.0	(0.4, 19.0)	17	5.9	(0.7, 34.3)
Central Forest	28	21.4	(8.9, 43.1)	13	30.8	(11.3, 60.8)
Northern Downs	28	28.6	(16.5, 44.8)	12	58.3	(29.2, 82.6)
Northern Forest	45	33.3	(20.5, 49.3)	26	46.2	(27.8, 65.6)
Mean wet season FP:ME<500 mg P/MJ ME						
Southern Forest	50	40.0	(24.3, 58.1)	19	52.6	(30.2, 74.0)
Central Forest	40	32.5	(16.8, 53.5)	13	53.8	(26.9, 78.7)
Northern Downs	35	68.6	(46.3, 84.6)	13	84.6	(52.7, 96.4)
Northern Forest	65	89.2	(74.5, 95.9)	26	96.2	(75.9, 99.5)

CI = Confidence interval.

Table 6-5. Proportion of heifers observed between 2008-2011 by risk factor category and country type.

Risk Factor	Southern Forest		Central Forest		Northern Downs		Northern Forest	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
*Body condition score at pregnancy diagnosis muster**								
N=	2743		2591		3822		8232	
≤2.0	2.6	(0.6, 11.1)	15.6	(1.7, 65.9)	6.4	(0.8, 37.6)	2.5	(1.0, 6.2)
2.5 to 3.0	26.7	(10.0, 54.5)	9.6	(3.0, 26.5)	32.0	(9.9, 66.8)	53.3	(35.8, 70.0)
≥3.5	70.7	(43.4, 88.4)	74.8	(31.9, 95)	61.7	(28.9, 86.5)	44.3	(26.9, 63.2)
Reproductive outcome								
N=	2120		2333		3235		5853	
Non-pregnant	25.8	(16.2, 38.5)	24.2	(11.7, 43.5)	22.5	(10.8, 41.1)	33.6	(19.5, 51.3)
Successfully Reared	68.6	(56.3, 78.7)	69.0	(50.8, 82.8)	65.0	(53.1, 75.3)	54.8	(38.7, 70.0)
Failed to Rear	5.7	(3.4, 9.2)	6.8	(4.6, 9.9)	12.4	(7.3, 20.4)	11.6	(7.7, 17.2)
Expected periods of calving								
N=	2139		2020		3030		5831	
Jul/Sep	56.2	(42.5, 69.1)	38.9	(18.6, 63.9)	9.1	(2.1, 31.4)	12.4	(4.6, 29.3)
Oct/Nov	34.6	(25.9, 44.5)	41.7	(31.1, 53.2)	41.0	(21, 64.5)	32.6	(25.9, 40)
Dec/Jan	8.6	(2.7, 23.9)	17.4	(6.4, 39.3)	31.8	(18.1, 49.7)	40.2	(29, 52.5)
Feb/Mar	0.3	(0.1, 1.7)	0.8	(0.2, 4.5)	14.5	(5.0, 35.1)	13.2	(7.8, 21.6)
Apr/Jun	0.2	(0.0, 1.5)	1.1	(0.1, 9.9)	3.6	(0.6, 19.1)	1.6	(0.9, 3.1)
THI exceeded 79 for >14 days during expected month of calving								
N=	2753		2592		3828		8273	
	34.5	(22.9, 48.2)	49.1	(24.3, 74.4)	89.4	(74, 96.2)	89.9	(81.2, 94.9)
Mustered around expected time of calving								
N=	1696		1,789		2,574		4,209	
	7.5	(2.6, 19.8)	11.2	(3.9, 28.2)	10.8	(2.8, 33.9)	5.8	(2.3, 13.7)
Hip Height								
N=	2284		2155		3354		3718	
Short	6.9	(2.4, 18.3)	2.6	(0.7, 9.3)	3.2	(1.1, 8.9)	8.0	(4.5, 13.9)
Moderate height	77.4	(71.6, 82.3)	69.2	(46.1, 85.5)	69.4	(40.3, 88.3)	79.2	(62.6, 89.7)
Tall	15.8	(10.4, 23.2)	28.2	(11.2, 54.8)	27.4	(8.9, 59.4)	12.8	(3.7, 35.9)

CI = Confidence interval
* mean interval from PD muster to predicted calving was 4.4 months.

Table 6-6. Proportion of first-lactation cows by risk factor category and country type.

Risk Factor	Southern Forest		Central Forest		Northern Downs		Northern Forest	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
*Body condition score at first annual branding/weaning muster**								
N=	1358		1646		1819		2320	
≤2.0	12.4	(4.3, 31.0)	22.5	(7.8, 49.9)	7.9	(2.7, 21.2)	32.2	(15.3, 55.4)
2.5 to 3.0	56.6	(42.2, 70.0)	40.0	(25.9, 55.9)	52.7	(37.7, 67.2)	59.3	(42.5, 74.2)
≥3.5	31.0	(18.8, 46.5)	37.5	(17.2, 63.5)	39.4	(21.6, 60.4)	8.5	(3.4, 19.7)
Body condition score at pregnancy diagnosis muster								
N=	1560		1584		1712		2342	
≤2.0	14.4	(6.4, 29.1)	8.8	(4.3, 17.1)	29.8	(15.7, 49.1)	31.0	(21.8, 42.1)
2.5 to 3.0	54.9	(43.7, 65.6)	55.4	(43.9, 66.4)	52.3	(42.5, 62)	59.4	(47.6, 70.2)
≥3.5	30.8	(20.7, 43.1)	35.8	(25.4, 47.7)	17.9	(9.4, 31.3)	9.6	(2.7, 28.8)
Change in body condition between pregnancy diagnosis and subsequent branding/weaning muster								
N=	1,352		1,645		1,723		2,293	
Lost	76.1	(54.4, 89.5)	78.0	(57.7, 90.2)	66.2	(46.5, 81.5)	79.1	(61.4, 90)
Maintained	14.9	(7.1, 28.5)	13.0	(6.6, 24.1)	22.3	(12.5, 36.5)	14.7	(7.3, 27.1)
Gained	9.0	(3.3, 22.6)	9.0	(3.1, 23.3)	11.5	(6.3, 20.3)	6.2	(2.7, 13.9)
Reproductive outcome								
N=	1130		1349		1362		1224	
Non-pregnant	28.9	(18.7, 42.0)	23.8	(16.1, 33.6)	33.2	(16.0, 56.3)	75.6	(50.6, 90.3)
Successfully Reared	66.8	(54.0, 77.6)	70.9	(61.3, 78.9)	62.2	(41.2, 79.4)	21.7	(8.7, 44.8)
Failed to Rear	4.2	(2.6, 6.8)	5.3	(3.6, 7.9)	4.6	(2.7, 7.7)	2.7	(1.1, 6.7)
Expected period of calving								
N=	1,204		1,200		1,225		725	
Jul/Sep	17.9	(8.2, 34.6)	15.1	(3.8, 44.3)	2.7	(0.6, 11.6)	1.7	(0.5, 5.9)
Oct/Nov	63.2	(47, 76.9)	51.5	(36.5, 66.3)	22.4	(8.1, 48.6)	29.8	(15.5, 49.6)
Dec/Jan	16.1	(8.8, 27.6)	30.9	(15.7, 51.9)	45.9	(33.1, 59.2)	24.8	(17.8, 33.4)
Feb/Mar	2.6	(0.8, 7.6)	2.5	(0.8, 7.7)	18.6	(9.7, 32.7)	17.9	(9.3, 31.7)
Apr/Jun	0.2	(0, 2.5)	0.0		10.4	(2.4, 35.3)	25.8	(12.6, 45.6)
THI exceeded 79 for >14 days during expected month of calving								
N=	1,595		1,668		2,297		2,556	
	45.3	(34.8, 56.1)	60.4	(45.5, 73.6)	93.7	(88.0, 96.8)	94.5	(87.7, 97.7)
Mustered around expected time of calving								
N=	865		1,026		914		330	
	5.2	(1.5, 16.1)	20.0	(5.3, 52.5)	32.8	(19.9, 49)	37.3	(23.4, 53.6)
Hip Height								
N=	1,393		1,577		1,973		1,645	
Short	5.4	(1.6, 16.9)	0.1	(0.0, 0.6)	0.8	(0.2, 4.3)	5.5	(2.5, 11.5)
Moderate height	69.5	(57.7, 79.2)	56.0	(32.4, 77.2)	59.6	(33.0, 81.5)	76.5	(53.1, 90.4)
Tall	25.1	(13.5, 42.0)	43.9	(22.6, 67.6)	39.6	(17.6, 66.8)	18.0	(5.0, 47.8)

CI = Confidence interval; *All females are lactating at the time of being visually assessed.

Table 6-7. Proportion of cows by risk factor category and country type.

Risk Factor	Southern Forest		Central Forest		Northern Downs		Northern Forest	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Lactated during the production year								
N=	12,166		9,965		22,926		29,170	
	91.2	(87.6, 93.8)	92.9	(88.2, 95.8)	88.5	(83.9, 91.9)	68.9	(65.2, 72.3)
Body condition score of lactating cows at branding/weaning muster								
N=	8,594		8,215		13,658		15,567	
≤2.0	9.7	(6.1, 15.1)	10.2	(4.2, 22.5)	7.1	(2.1, 21.1)	28.7	(18.2, 42.0)
2.5 to 3.0	54.5	(45.6, 63.2)	45.7	(34.5, 57.4)	61.2	(49.8, 71.5)	60.9	(48.3, 72.1)
≥3.5	35.8	(25.7, 47.3)	44.1	(29.0, 60.4)	31.7	(25.4, 38.8)	10.5	(7.4, 14.7)
Body condition score of non-lactating cows at branding/weaning muster								
N=	1,057		744		1,876		10,527	
≤2.0	2.6	(1.1, 6.1)	2.4	(1.0, 5.9)	0.7	(0.2, 2.6)	2.3	(0.7, 6.7)
2.5 to 3.0	25.7	(10.1, 51.7)	13.2	(6.8, 23.9)	10.6	(5.5, 19.3)	27.2	(21.9, 33.3)
≥3.5	71.6	(45.2, 88.6)	84.4	(73.3, 91.4)	88.7	(79, 94.2)	70.5	(63.1, 77.0)
Body condition score at pregnancy diagnosis muster								
N=	12,144		10,119		26,066		30,035	
≤2.0	9.9	(5.6, 17.0)	9.7	(3.0, 27.2)	11.8	(3.5, 32.5)	24.3	(16.6, 34.0)
2.5 to 3.0	40.3	(32.2, 48.9)	34.5	(24.5, 46.0)	39.9	(37.8, 42.1)	52.6	(42.3, 62.6)
≥3.5	49.8	(38.4, 61.2)	55.8	(41.5, 69.2)	48.3	(35.1, 61.8)	23.1	(18.8, 28.1)
Change in body condition of lactating cows between pregnancy diagnosis and subsequent branding/weaning muster								
N=	4,578		5,564		8,929		7,630	
Lost	43.0	(36.0, 50.3)	37.5	(31.2, 44.1)	46.8	(37.8, 55.9)	57.1	(50.8, 63.2)
Maintained	25.3	(21.6, 29.5)	28.5	(24.1, 33.4)	29.9	(22.2, 39.0)	23.0	(19.8, 26.5)
Gained	31.7	(24.3, 40.1)	34.0	(29.0, 39.5)	23.4	(10.5, 44.2)	19.9	(13.9, 27.6)
Reproductive outcome								
N=	6,798		6,122		16,278		17,767	
Non-pregnant	16.7	(10.3, 25.8)	13.9	(7.6, 23.9)	17.6	(15.6, 19.8)	42.2	(38.4, 46.1)
Successfully Reared	77.0	(68.0, 84.0)	79.6	(71.2, 86.1)	73.7	(70.3, 76.9)	48.9	(45.8, 52.0)
Failed to Rear	6.4	(4.4, 9.2)	6.5	(4.8, 8.8)	8.7	(6.6, 11.3)	8.9	(6.4, 12.3)
Expected period of calving								
N=	10,225		8,665		21,998		18,065	
Jul/Sep	34.7	(22.1, 50.0)	13.9	(8.3, 22.5)	3.7	(1.1, 11.6)	8.7	(4.4, 16.3)
Oct/Nov	40.4	(31.0, 50.5)	54.7	(46.0, 63.1)	19.4	(12.9, 28.1)	34.7	(30.3, 39.3)
Dec/Jan	17.2	(9.9, 28.2)	30.2	(19.2, 44.1)	45.1	(36.0, 54.5)	31.8	(27.2, 36.9)
Feb/Mar	5.1	(1.8, 13.4)	1.2	(0.5, 2.7)	18.0	(13.3, 23.9)	15.4	(11.9, 19.7)
Apr/Jun	2.6	(0.8, 8.2)	0.0	(0.0, 0.2)	13.8	(7.8, 23.3)	9.4	(6.9, 12.7)
THI exceeded 79 for >14 days during expected month of calving								
N=	13,753		10,812		28,827		33,772	
	50.9	(39.6, 62.1)	65.3	(57.3, 72.5)	90.1	(83, 94.4)	93.9	(89.8, 96.4)
Mustered around expected time of calving								
N=	6,149		5,305		13,638		10,813	
	12.9	(7.8, 20.8)	13.3	(6.2, 26.3)	14.3	(7.7, 25.2)	12.0	(7.8, 18.2)
Hip Height								
N=	10,223		7,915		11,535		18,452	
Short	4.3	(2.0, 8.7)	6.5	(0.9, 34.3)	0.6	(0.3, 1.3)	2.4	(1.0, 5.6)
Moderate height	71.0	(61.6, 78.9)	52.0	(41.7, 62.2)	60.4	(44.9, 74.0)	74.4	(70.1, 78.3)
Tall	24.7	(17.3, 34)	41.5	(29.4, 54.6)	39.0	(25.3, 54.7)	23.1	(18.2, 28.9)

CI = Confidence interval

6.5 *Discussion*

The data presented in the present study is distinctive as it involved a large number of commercial beef breeding herds that were monitored using standardised approaches.

However, it is recognised that participation bias may exist within this dataset as due to logistical constraints completely random selection of participants was not possible. The cooperating properties and herds were a convenience sample that met a selection criterion of annually pregnancy testing the entire herd, which is not standard practice within some parts of northern Australia. Therefore, appropriate caution should be exercised when interpreting results as they may reflect those of a population operating slightly above typical and despite appropriate diligence being placed on recording of data there were some practical limitations of capturing observational data under commercial conditions.

The interval to follow-up rain after wet season onset and minimum available dry season biomass are reported as major determinants for incidence of pregnant cows missing (Fordyce *et al.* In press). The incidence of cow mortality was estimated to be higher for the northern regions of Northern Australia (Henderson *et al.* 2013; Fordyce *et al.* In press). In the present study the percentage of study properties reporting minimum average available dry season biomass <2000kg/ha in at least one year was slightly higher in the Northern Forest, compared to other country types. However, long intervals (>30 days) to follow-up rain after wet season onset tended to occur less frequency for properties within the Northern Forest. Reported by O'Rourke (1994), most cow deaths occur between the late dry and early wet seasons, coinciding with calving and lactation, and peak nutritional requirement. The present study found that the proportion of cows in low body condition prior to calving was greatest within the Northern Forest and quick transitions between the late dry to early wet potentially increases the risk of cow mortality due to low pasture base, lactation and potentially pregnancy.

The ratio, DMD/CP, has been reported to be a useful indicator of whether rumen fermentation and pasture intake are likely to be limited by effective rumen degradable protein supply (Dixon and Coates 2005). Evidence from field trials suggest that in general, responses to rumen degradable nitrogen supplements are expected when the DMD/CP ratio, at least for speargrass pastures, is greater than 10 and is likely when the DMD/CP is greater than 8 (Dixon and Coates 2005). The average wet season DMD/CP using the cut point ≥8:1 was identified as a major determinant for cows failing to become pregnant and P4M (Chapter 7 and Chapter 8). This study found that study properties rarely appeared to be limited by rumen function between Nov-Apr within the Southern Forest. In contrast, approximately 1/3 of study properties within the Northern Forest and Northern Downs in any year appeared to be potentially limited by the availability of rumen degradable protein during the wet season. Field trials have described similar findings, McCosker *et al.* (1991) reported cow fertility, weight and growth responses to the provision of supplemental non-protein nitrogen to breeding cows in the NT.

Phosphorus (P) is a key factor in animal production in northern Australia (Miller *et al.* 1990). Cattle grazing P deficient situations can develop signs of aphosphorosis such as reduced appetite, growth rate reproductive performance and milk yield, bone abnormalities, and stiffened gait (also known as 'peg leg') (Winks 1990). The ratio of faecal P to estimated metabolisable energy (calculated from estimated DMD) (FP/ME) was used as a risk factor describing the risk of P deficiency adversely affecting performance (Jackson *et al.* 2012). The risk factor describing the risk of P deficiency likely to affect reproductive performance was identified as an important determinant for probability of P4M (Chapter 7), non-pregnancy (Chapter 8) and foetal/calf loss (Chapter 9). Study herds within the Northern Forest, had more frequent occurrences P deficiency likely to affect reproductive performance than other country types and is largely consistent with previous reviews of the literature (Kerridge *et al.* 1990). In the Northern Downs, the current study found that high risk of P deficiency affecting reproductive performance was determined for a number of properties and a number of years although its occurrence was less consistent when compared to Northern Forest.

Wild dogs are prevalent throughout all beef production areas of Northern Australia (West 2008) and are estimated to cause annual production losses of $23.4M (Fleming *et al.* 2012). This study found that approximately 20% within Southern Forest and less than 10% in other country types considered wild dogs as having little or no impact on their herd's reproductive performance and conversely, the majority of producers attempted to actively control the wild dog population. This potentially somewhat confounded by legislation making wild dog control compulsory for Western Australia and Queensland study participants. However, the most effective method to control wild dogs is currently under some debate. Allen (2014) reported findings that the use of conventional methods to control wild dog populations possibly results in an increased risk of calf predation.

The variation in expected periods of calving across country types is explained by mating management. Bulls were typically mated for restricted periods of time within both the Southern and Central Forest. The spread of calving was greatest within the Northern Downs and Northern Forest. Within the Northern Forest in particular, only a small percentage of first-lactation cows were diagnosed as being pregnant, of which an alarming proportion (~25%) were expected to calve during Apr/Jun and are likely to have occurred in response to weaning their first calf during May/June. Cows calving at inopportune times of the year, particularly low conditioned young cattle, are of increased risk of mortality (O'Rourke 1994). Reproductive traits measured at a females second mating have reported recently reported to be strongly correlated with lifetime performance (Johnston *et al.* 2013). Therefore, females demonstrating the ability to become pregnant as a first-lactation cow are likely to exhibit favourable lifetime reproductive performance and therefore, should be managed reduce their risk of mortality. A practical implication from this finding could be that producers identify, separate and manage accordingly pregnant first-lactation cows to ensure their risk of mortality is reduced.

Body condition as a useful indicator of the energy status of cattle and its association with reproductive performance and cow mortality has been well established and documented (Entwistle 1983; Burns *et al.* 2010). In the present study, it was generally found that the distribution of body condition score categories allocated prior to calving was lower for first-lactation cows than for lactating multiparous cows. A trend that appeared influenced by country type as even though first-lactation cows have heightened nutritional requirements to support maternal growth as well as lactation, the distribution of body condition scores assigned to lactating multiparous cows was comparable with those cows experiencing lactation for the first time. This finding is partially explained by the limited nutritive value of Northern Forest, and potentially suggests they are unable to support the nutritional demands of lactation irrespective of other additional nutritional requirements. However, it was found that even though multiparous cows had similar body condition at pregnancy diagnosis than first-lactation cows, a higher proportion of lactating multiparous cows gained condition between pregnancy diagnosis and the subsequent branding/weaning muster. This effect appeared across country types, with cows within the Northern Forest less likely to gain or maintain condition and cows within the Southern Forest most likely to gain or maintain condition.

Mustering efficiency and mustering around the time of calving were risk factors associated with the risk of foetal/calf loss (Chapter 9). The percentage of cows and heifers mustered around the time of calving appeared to be relatively consistent across country types. The percentage of first-lactation cows mustered around the time of calving (ie at the time delivering their second calf) appeared to be slightly elevated when compared to other cow age groups and is potentially explained by the expected periods of calving occurring slightly later in the calving season than for other age classes. A practical implication of this finding is that some potential benefit may exist if producers allowed for the likely increase in time to conception from calving in first-lactation cows and therefore, adjusting their mustering schedules reducing prevalence of cows being mustered around the time of their second calving.

The reason for low mustering efficiency and increased calf loss is unclear, and potentially may be partly explained due to females self-weaning and misclassification of lactation status. Study properties averaging >10% of females absent at a muster per year were only identified in the Southern and Northern Forest country types. Fifteen percent of study properties observed with absenteeism rates exceeding 10% is an unanticipated result and is partly explained by periods of extended dry and large rainfall events causing widespread flooding within this region during the study period. Due to the extensive nature of management systems within the Northern Forest and cows calving throughout the year, heightened rates of cows not being mustered throughout a year is not unexpected by the authors.

A temperature-humidity index (THI) threshold of 79 for ≥15 days during the expected month of calving was determined as an important predictor of risk of foetal/calf loss (Chapter 9). The prevalence of cows and heifers expected to calve in months at risk of high heat load were consistent across cow-age classes within country types. Less than 65% of heifers and cows within the Southern and Central Forest were predicted to calve in months that were at risk of causing a high heat load. Conversely, approximately ≥90% of study heifers and cows within the Northern Downs and Forest were predicted to calve in months that were at risk of causing a high heat load.

Hip Height has been determined as an important predictor for risk of foetal/calf loss and expected occurrence of P4M (Chapter 7 and Chapter 9). Generally, the prevalence of short cows was consistent across country types. However, a higher prevalence of tall cows was observed in the Central Forest and Northern Downs country types, while a greater proportion of heifers and cows observed within the Southern and Northern Forest were of moderate height . The distribution of hip height is possibly largely explained by the breed base of the study herds. Heifers and cows within the Southern Forest generally included a high proportion of British *Bos taurus* genotypes, while typically increased use of European *Bos taurus* breeds within Central Forest and Northern Downs was common and within the Northern Forest cattle largely contained a high percentage of *Bos indicus* content.

6.6 Conclusions

The descriptive results presented in the present paper provide information on data employed to conduct the multivariate analyses identifying the major associations between management, nutritional, environmental and female risk factors and reproductive performance and are covered in companion papers included as Chapters 7-9 in this thesis and Fordyce *et al.* (In press).

Unfavourable levels of risk factors were observed in all country types and across all cow age groups. Study properties within the Southern Forest rarely appeared to be limited by rumen function between Nov-Apr while, approximately one third within the Northern Forest and Northern Downs in any year appeared to be potentially limited by the availability of rumen degradable protein during the wet season. Additionally, the occurrence of P deficiency likely to affect reproductive performance was greater in the Northern Forest than other country types with nearly all properties being categorising as 'high risk' for one or more years.

Generally, an elevated percentage of heifers and cows within the Northern Forest tended to be exposed to adverse levels or displaying unfavourable attributes of risk factors when compared to other country types. Heifers and cows within the Northern Forest tended to be observed in less than adequate body condition prior to calving, were more likely to calve in unfavourable times of the year and less likely to gain weight between the pregnancy diagnosis muster and branding/weaning muster.

6.7 Contributions by others to the chapter

Mr McCosker was responsible for the management of the data across all country types and capturing the data within the country type of Northern Forrest. Mr Smith with the assistance of Mr McCosker was responsible for collating the NIRS and mapping data across all country types. Mr McCosker, under the oversight of Professor O'Rourke, led the analysis and interpretation of the data and was responsible for the writing of the chapter. Professor McGowan led the trial design in conjunction with Professor O'Rourke. Professor McGowan, Dr. Fordyce, Professor O'Rourke, and Mr Smith have also had a substantial intellectual contribution to the interpretation of the data.

Chapter 7 Factors influencing the occurrence of lactating cows becoming pregnant within four months of calving

7.1 Abstract

A prospective epidemiological study was conducted in a selected population of commercial beef breeding herds in northern Australia. Approximately 78,000 cattle managed in 78 herds were monitored for 3 to 4 years. The resulting dataset was analysed to determine and quantify the major associations between herd management practices, nutritional and environmental factors, and individual cow attributes, and the probability of lactating cows being pregnant within four months of calving (P4M). P4M accurately estimates the proportion of cows in a herd which will potentially wean a calf in consecutive years. The mean percentage of lactating cows pregnant within 4 months of calving for beef herds within the study population was 41.6% of cows per production year.

The analysis of data was based on four broad country types derived from estimates by the collaborating herd manager of annual growth of yearling steers grazing similar pastures to those of heifers and cows in the study. Within these country types mean percentage of lactating cows pregnant within 4 months of calving was estimated at 65.4%, 57.5%, 61.8%, and 16.4% for the Southern Forest, Central Forest, Northern Downs and Northern Forest, respectively. After partitioning the effects of other factors in the selected model, the associated effect of cow-age class cohort on lactating cows pregnant within 4 months of calving was dependent on country type with the expected occurrence of P4M for first-lactation; second-lactation; and mature and aged cows, 7.1%, 5.6% and 14.1-15.2%, respectively within the Northern Forest. This was estimated as 23.1-53.8, 38.1-61.6 and 35.4-59.4 percentage points lower, respectively when compared to other country types.

When all other factors were taken into account the estimated mean percentage of lactating cows pregnant within 4 months of calving varied by 49 percentage points with cows predicted to calve between July and September 15% compared to those cows predicted to calve in December-January (64%). Wet season pastures of adequate protein content and risk of phosphorus deficiency were also determined to influence the occurrence of lactating cows pregnant within 4 months of calving with an estimated 20.3 percentage point higher mean percentage lactating cows pregnant within 4 months of calving in first lactation cows where risk of phosphorus deficiency was low compared to where risk of phosphorus deficiency was high. For cows grazing wet season pastures of low protein content (>8:1 DMD:CP ratio) a 12.7 percentage point lower mean percentage lactating cows pregnant within 4 months of calving was estimated when compared to grazing pastures of adequate protein content (≤8:1 DMD:CP ratio). Mean percentage lactating cows pregnant within 4 months of

calving increased in each year of observation with estimated differences ranging between 3.3-11.7 percentage points across years.

This study verified that the exposure of bovine viral diarrhoea virus (pestivirus) at critical times has major impact on the occurrence of lactating cows pregnant within 4 months of calving and was estimated as 23.0 percentage points lower for cows within groups with high bovine viral diarrhoea virus seroprevalence (>80% seropositive) compared to those within groups with a low seroprevalence (<20% seropositive).

The findings of the present study highlight the critical importance of ensuring the majority of cows within a herd calve at a time of the year when nutrition from pasture supports lactation and later re-alimentation after weaning, and managing cattle such that they are in good body condition prior to calving. These findings also suggest that whilst there is clear evidence that infectious diseases can significantly impact the reproductive performance of beef herds within northern Australia, generally other nutritional, environmental and management factors explained greater proportion of the variation between herds.

7.2 Introduction

Approximately half of Australia's beef breeding herds are located in northern Australia which includes the state of Queensland, the Northern Territory and the northern part of the state of Western Australia. This is a subtropical-tropical region with a characteristic wet and dry season dominated by a summer rainfall pattern. Soil fertility is highly variable with most areas north of the Tropic of Capricorn being considered at least marginally phosphorus deficient. Many areas in central and southern Queensland have moderate to high fertility soils. Beef cattle graze either improved tropical pastures or native pastures that vary considerably in dry matter digestibility and crude protein content according to season. In northern Australia, approximately 85% of beef cattle have some *Bos indicus* content to enable them to better cope with high environmental temperatures, low quality pastures and internal and external parasitism, in particular cattle tick (*Rhipicephalus microplus*) and buffalo fly (*Haematobia irritans exigua*) infestation. Cattle are typically mustered (brought together from the paddock into a cattle handling facility) twice a year for branding, weaning and other husbandry such as pregnancy diagnosis, usually in the late wet-early dry season and then again in the mid-dry season. Helicopter mustering is now commonly used on most extensively managed properties. Approximately two-thirds of cow herds in the dry tropical rangelands of northern Australia are continuously mated, whereas in areas with higher soil fertility and more intensive management herds are control mated, typically for periods of 3 to 7 months.

The beef industry in northern Australia has recently been reported to be in an unprofitable and unsustainable state with many beef enterprises tending to spend more than earnings in six of the previous seven years (McCosker *et al.* 2010b). Productivity of the beef breeding component of a beef herd (reproductive productivity) is a function of the annual percent of cows mated weaning calves and the live weight of calves at weaning (Arthur *et al.* 1999). Since the efficiency with which lactating cows become pregnant influences both the annual percentage of calves weaned and the live weight of calves at weaning, the average interval between calving to the establishment of their next pregnancy is a significant determinant of the productivity and profitability of north Australian beef herds (Braithwaite and deWitte 1999a).

For north Australian beef herds, the percentage of cows annually contributing a calf is often low ranging between 50-70% (Burns *et al.* 2010), which is largely attributed to prolonged post-partum anoestrus interval (Entwistle 1983; Fordyce *et al.* 1997). Studies have reported the impacts of biological, breeding management and individual cow risk factors on the post-partum anoestrus interval (PPAI) of beef cattle, including the impact of parity, body condition score at calving, plane of nutrition, season of calving and genotype (Baker 1969; Short *et al.* 1990; Yavas and Walton 2000; Montiel and Ahuja 2005; Blanc and Agabriel 2008; Hawken *et al.* 2012). However, there have been few epidemiological studies that have determined and quantified the factors affecting the occurrence of commercially managed beef cows becoming pregnant whilst lactating.

The primary objective of this study was to identify the major associations between herd management practices, nutritional, environmental and infectious disease factors and individual cow attributes, and the probability of lactating cows being pregnant within four months of calving on commercial beef cattle breeding properties in northern Australia.

7.3 Materials and methods

A comprehensive description of the methodology used in the present study is provided by McGowan *et al.* (2014). The study was conducted between 2007 and 2011.

7.3.1 Ethical clearance

Ethical clearance (AEC approval number SVS/756/08/MLA) was obtained from the University Animal Ethics Committee (Production and Companion Animal), The University of Queensland.

7.3.2 Overview of study design

A prospective population-based epidemiological study was conducted in commercial beef breeding herds in northern Australia. Seventy-eight properties (farms) located across each of the major beef breeding regions of Queensland, the Northern Territory and Western Australia participated in the project (Figure 1). Potential collaborating herds were identified by project regional coordinators or collaborating veterinarians as meeting the following criteria: 1) Only herd managers who were keen to participate and support the project and thought likely to maintain accurate records were included. 2) Properties were selected that were considered to be typical in their region for their property size and herd management. 3) Herd managers were prepared to maintain the enrolled management groups on their property, with the exception of females culled as per normal property breeding herd management policy, for the duration of the study. 4) All enrolled females were individually electronically identified for the duration of the study. 5) The herd manager was prepared to attend a one-day training workshop in assessing standing pasture biomass and land condition. 6) Properties had access to reasonable working condition cattle handling facilities and, herd managers were prepared to ensure that all enrolled management groups were mustered a minimum of twice a year, once at the time of branding and/or first annual weaning muster and then again for pregnancy diagnosis either at least six weeks after the bulls were withdrawn or in continuously mated herds at the time of the second (final) annual weaning muster which is usually conducted during the mid-dry season (August-October). 7) All pregnancy diagnosis and foetal aging of enrolled management groups was conducted by cattle veterinarians 8) Properties had access to weighing facilities and at a minimum, were prepared to record the individual live weight and associated information for weaners from each enrolled herd at each weaning muster.

Cooperating properties were progressively enrolled over 2 years. Initially, a pilot study involving 13 properties was undertaken with each property enrolling a management group of selected maiden heifers during 2007-2008 to inform the management and design of the larger observational study that was conducted during 2009-2011. Each cooperating property typically enrolled two cohorts of females, a management group of heifers that were planned to be exposed to bulls for the first time and a management group of mature cows. All females were enrolled in groups of between 100 to

500 females. However, in management groups that were larger than 500 females, a cross-sectional subset of 300 females was enrolled.

7.3.3 Potential risk factors assessed

Heifers and cows were individually identified using National Livestock Identification System (NLIS; www.nlis.com.au) tags. NLIS tags were replaced if the tag was missing or was present but could not be read. In the event of a NLIS tag being replaced, data linkages to previous performance records were often able to be established as study animals were individually identifiable by a visual identification ear tag.

Performance and explanatory data were recorded twice a year for each cow enrolled into the project, at the main branding or weaning muster and again (approximately 4 to 5 months later) at the pregnancy diagnosis (PD) muster. Enrolled heifer cohorts were mustered once a year for pregnancy diagnosis and when they calved for the first time they were reclassified as first-lactation cows. At a study animal's first muster information on estimated percentage of *Bos indicus*, content, year brand and hip height (Fordyce *et al.* 2013a) were recorded. At each muster, body condition score (Gaden *et al.* 2005), lactation status were assessed and recorded. Also, wherever possible liveweight was measured at each muster. Foetal age was recorded for all cows at the pregnancy diagnosis muster; the mean interval from PD to predicted calving was 4.4 months.

Management and resource factors were derived from survey responses provided by the cooperating herd manager at the commencement of the study. A uniform interpretation of questions and responses was ensured by using a face-to-face survey method. The questionnaire contained 148 items including descriptors of the property (eg. property area, herd size, average rainfall), and grazing and herd management practices and policies (eg. bull percentage, duration of mating, culling and selection policies, provision of supplements, weaning and vaccination policies).

Nutritional factors were derived from faecal near-infrared spectroscopy (NIRS) (Dixon and Coates 2010) and wet chemistry faecal phosphorus (FP) (Jackson *et al.* 2012) analysis of faecal samples collected in January, March, May, August November, and herd manager pasture assessments. The ratio between phosphorus and metabolisable energy (FP:ME) was used to indicate whether there was sufficient phosphorus in the diet (Jackson *et al.* 2012; Quigley *et al.* 2015) and the ratio between dry matter digestibility to dietary crude protein (DMD:CP) as an indicator of rumen degradable protein limiting pasture intake and rumen function (Dixon and Coates 2005). Annual property rainfall and weather interpolations were obtained from the Australian Bureau of Meteorology. Cattle movements were documented by the cooperating herd manager and paddock factors (paddock area, distances to water) were generated within a geographic information system (ArcView).

Infectious disease factors were derived from cross sectional blood and vaginal mucus sampling of enrolled cows and heifers (approximately 15 to 30 animals per management group) . Blood samplings were performed at both the branding or weaning muster and pregnancy diagnosis muster, while vaginal mucus samplings were performed at the pregnancy diagnosis muster in the production years of 2009 and 2011. Serological testing for bovine viral diarrhoea virus (BVDV), bovine ephemeral fever (BEF) virus, *Leptospira borgpetersenii* serovar *hardo* type Hardjobovis (*L.hardjo*), *Leptospira interrogans* serovar *pomona (L.pomona)*, *Neopsora caninum* and *Campylobabcter fetus subsp. venerealis* infection was conducted (McGowan *et al.* (2014).

7.3.4 Regionalisation of properties – country type

Data from each property was regionalised according to four country types used to describe the production potential of the grazing land utilised during the study. Properties were assigned to one of four broad country types following a subjective assessment of the production potential of the grazing land and cross-referencing with pasture and vegetation descriptions reported by the herd managers. Property managers were asked to provide an estimate of the annual growth of yearling steers (AGYS) for the country where the cattle enrolled in the study were grazed. Properties with forested land-types with fertile soils in the central and south-east regions of Queensland were differentiated by being outside (Southern Forest; median AGYS 200kg) and within (Central Forest; median AGYS 180kg) the northern Brigalow Forest. In the northern areas of Queensland, Northern Territory and Western Australia, properties with land types that were predominantly large treeless black soils plains (Northern Downs; median AGYS 170kg) were segregated from those with forested land-types and low fertility soils (Northern For; median AGYS 100kg est).

7.3.5 Deriving the outcome pregnant within four months of calving in lactating cows (P4M)

P4M was summarised for each annual production cycle and was defined as the cumulative percentage of cows that became pregnant within four months of calving with 0=failed to be pregnant within four months of calving and 1=pregnant within four months of calving. With the period from the end of one pregnancy diagnosis muster to the end of the pregnancy diagnosis muster in the following year, which was conducted approximately 12 months apart, defining an annual production cycle. Only those cows that successfully reared their first confirmed pregnancy after enrolment were eligible for this outcome variable to be generated.

The date of calving and the date of conception following calving, which were then used to generate P4M, were estimated based on results of foetal ageing following manual rectal palpation of the reproductive tract by experienced cattle veterinarians who were all members of the Australian Cattle Veterinarian's National Cattle Pregnancy Diagnosis Scheme. The predicted month of calving was calculated using estimated foetal age at the date of the pregnancy diagnosis muster and projected forward using an assumed gestation length of 287 d. As foetal age was recorded in months, it was multiplied by 30.4 days per month to estimate foetal age in days. The predicted date of conception was then estimated using the foetal age data from the pregnancy diagnosis muster in the current year. Females that had conceived in less than 108d (ie expected to have a ≤13 m inter-calving interval) were defined as being positive for P4M.

Animals were not eligible for classification under P4M if they were recorded as having been not-pregnant in the previous annual reproductive cycle (period of approximately 12 months between consecutive annual pregnancy diagnosis musters), or if they failed to lactate after being previously diagnosed pregnant i.e experienced foetal or calf loss. Females were recorded as successfully rearing a calf if they were diagnosed as being pregnant and were then recorded as 'lactating' after the expected calving date. Females were recorded as having failed to rear their pregnancy if they were recorded as being not lactating ('dry') at the first muster after the expected calving date, provided this muster occurred greater than one month after the expected month of calving, and they were not subsequently recorded as lactating.

7.3.6 Data management and statistical analyses

At each site, animal data were collected at the time of mustering using commercially available automated data collection systems, such as AgInfoLink's BeefLink™ program, that captured data against individual electronic animal identification and interfaced with liveweight scale. Records were managed using a relational database (Microsoft Access 2010 for Windows; Microsoft Corporation, Washington, USA) and a spreadsheet system (Microsoft Excel 2010 for Windows; Microsoft Corporation, Washington, USA). All statistical analyses were performed using StataIC® (versions 13 for windows; Stata Corporation, Texas, USA) with one animal production year for an animal as the unit of analysis.

Screening of risk factors for inclusion in the multivariable model building process was based on associations between potential risk factors and P4M using a random-effects logistic regression model with Stata's -xtlogit- command, fitting herd as a random effect. The overall significance of risk factors were assessed using Wald-test P values. Risk factors were retained for consideration in the multivariable model building process if their association with the outcome was significant at $P \leq 0.20$ (Dohoo *et al.* 2009).

The assumption of linearity of continuous variables in the logit were evaluated by inspecting partial residual graphs following herd-adjusted logistic regression models fitting the continuous variables as the main effect of non-pregnancy using Stata's –lpartr- command (Hilbe 2009). Continuous variables that appeared to fail the assumption of linearity were categorised into two or more categories. Wherever possible, continuous variables were categorised using established threshold values. However, in some cases, where these were not found to be discriminatory, cut points were determined by changes in the slope of cubic splines fitted to partial residual plots.

Examination of pairwise Spearman correlations were used to identify pairs of risk factors that were highly correlated ($r \geq 0.90$) (Dohoo *et al.* 2009). Where pairs of risk factors were highly correlated, one risk factor was selected for inclusion in the multivariable model building process on the basis of biological plausibility, fewer missing values and Akaike's and Schwarz's Bayesian information criteria estimates. Putative risk factors that had an excessive number (≥ 40%) of missing values were also considered ineligible for consideration in the multivariable model building process.

A multivariable model was built using a backwards elimination process. Commencing with all significant ($P \leq 0.20$) risk factors derived from candidate variable screening being added to a starting model, non-significant variables with the highest P value were dropped one at a time. This process was continued until only significant ($P \leq 0.05$) variables remained in an interim model. With the exception of those variables with a high degree of missing values, all risk factors previously eliminated during the model building process were again reconsidered, one at a time, for inclusion into the interim model. The predictor -country type- was forced into all interim models due to specific interest in the effects of region that were being represented by -country type-. All potential interactions between pairs of risk factors remaining in the interim model were considered one at a time and were retained in the final model if their association was significant ($P \leq 0.05$) and their effects biologically plausible. An appraisal of effects of potential confounding variables was completed by individually including each variable into the candidate model and assessing changes in the measure of association for statistically significant variables. Confounding was considered important when odds ratios for statistically significant variables changed by >20-30% ((Dohoo *et al.* 2009) and the variable was included in the final main effects model.

The fit of the multivariable model was evaluated and observations that did not fit the model well (outliers) or having an undue influence on the model were identified. The overall goodness-of-fit of multivariable model was assessed using Hosmer-Lemeshow goodness-of-fit tables and statistics (Hosmer *et al.* 2013). Outliers were identified by an analysis of the residuals and models with and without the influential observations were compared.

Following fitting the final multivariable model, estimated marginal means of risk factors were computed using Stata's -margins- postestimation command. Standard errors were obtained using the delta method. Differences between estimated marginal means across levels of each risk factor or interaction term were estimated and statistically compared using linear combinations of estimators and pairwise comparisons, respectively using Stata's -pwcompare- postestimation command.

7.3.7 Population attributable fractions

The population attributable fraction for each of the risk factors retained in the final multivariable model was estimated to provide a measure of the relative importance for each risk factor contained within the final multivariable model. After recoding the outcome variable to reflect cows not becoming pregnant by four months after calving rather than P4M, a logistic regression model, clustered by herd, containing the main explanatory factors that were retained in the multivariable model and not including any interactions, was used to estimate the population attributable fractions for each risk factor using Newson (2010) Stata command –punafcc-.

7.3.8 Effects of risk factors not contained in the final model.

Infectious disease risk factors, which were derived from cross sectional blood and vaginal mucus samplings performed in two of the three study production years, had >40% missing values and therefore were ineligible for inclusion in the main multivariable modelling. Thus, the potential effects of risk factors summarising management group prevalence of seropositives and management group prevalence of recent infection with BVDV, *N. caninum*, BEF virus, *L. hardjo*, L. *pomona*, and C. *fetus* subsp. *venerealis* were estimated by solely adding each risk factor to the final model. Additionally, due to sampling procedures in management groups >300 cows in size hip height, which was measured at the first pregnancy diagnosis muster, also contained >40% missing values and was not included in the model building process.

7.4 Results

7.4.1 Description of study population

The starting dataset contained 35,902 rows of data representing a production year for an individual cow. On average, each individual cow and heifer contributed 1.3 (95% CI, 1.3-1.4) and 1.5 (95% CI, 1.4-1.5) animal-production years of data that a valid P4M outcome was ascribed. Seventy-three herds contributed information to the starting dataset with a median of 293 (IQR, 188-502) P4M outcomes relating to an individual herd.

The population-averaged P4M, with adjustment for clustering at the herd-level, was 41.6% (95% CI, 32.3-50.5%) of cows per production year using the null model. P4M varied greatly between country types with the mean P4M being 65.4% (95% CI, 53.1-77.7%), 57.5% (95% CI, 44.8-70.2%), 61.8% (95% CI, 48.1-75.6%), and 16.4% (95% CI, 10.7-22.1%) for the Southern Forest, Central Forest, Northern Downs and Northern Forest, respectively. The proportion of the variation explained at the herd-level in the null model for P4M was 0.38.

7.4.2 Univariable associations

The candidate risk factors that were considered during univariate screening and progressed into the multivariable modelling process are presented in Table 7-1 (Results of herd-adjusted logistic regression models to screen candidate risk factors by including each candidate risk factor as a single main effect term is presented as additional material in Section 7.8.1). Factors that had associations with P4M which were found to be not statistically significant and therefore, did not progress into the final multivariable model building process were: average wet season dietary crude protein content of the pasture less (<7%/≥7%), herd BVDV vaccination policy (Heifers/Herd/Not Vaccinated) and the reported bull:female ratio (<3:100/≥3:100) during the breeding season.

Table 7-1. List of candidate risk factors for the probability of lactating cows being pregnant within four months of calving (P4M) that were considered during univariate screening and progressed into the multivariable modelling process

Risk Factor*	
Herd management	
Percentage *Bos indicus* of heifers & cows Property management experience of manager Reported size of the herd Average size of management group at pregnancy diagnosis Bull selection policy Annual bull management policy	Culling rate of breeding females Culling age of breeding females Mating management Botulism vaccination policy Leptospirosis vaccination policy Bulls vaccinated for bovine empheral fever
Environment	
Year observed Timing of wet season onset Wet season duration Cumulative number of days maximum temperature exceeded 32°C during month of calving Cumulative number of days maximum temperature exceeded 39°C during month of calving	Cumulative number of days temperature humidity index exceeded 71 during month of calving Cumulative number of days temperature humidity index exceeded 79 during month of calving Average temperature humidity index during month of calving
Nutrition	
Minimum dry season biomass Average dry season crude protein (CP) Average dry season dry matter digestibility (DMD) Average dry season DMD:CP Provision of supplemental nitrogen Provision of supplemental phosphorus Proportion of the paddock grazed which was ≤2.5 km from permanent water around time of calving	Average wet season CP Average wet season DMD Average wet season DMD:CP ratio Average ratio faecal phosphorus to metabolisable energy during wet season
Animal	
Cow-age class Estimated period of calving Liveweight at the pregnancy diagnosis muster Body condition score (BCS) at the pregnancy diagnosis muster	BCS at the branding or weaning muster BCS change between pregnancy diagnosis and branding or weaning musters Hip height

7.4.3 Multivariable model results

The final model included data representing 25,070 animal production years from 58 herds; 30.2% of animal production years and 20.5% of herds with valid entries for the outcome P4M were not represented in the final model because of missing values for one or more risk factors. In the final multivariable model (Table 7-2), there was an effect of country type, production year, cow-age class, estimated period of calving, body condition score at the time of pregnancy diagnosis and its change through to subsequent weaning/branding of the calf and average ratios of faecal phosphorus to metabolisable energy and dietary crude protein to dry matter digestibility of pastures measured across the wet season.

Table 7-2. Adjusted odds ratios, 95% confidence intervals and *P* values from a multivariable logistic regression model of risk factors for probability of lactating beef cows being pregnant within four months of calving (P4M) in northern Australia. Data drawn from 25,070 animal production years involving 19,238 individual cows from 58 herds.

Variable	Coefficient	SE	Adjusted OR	95% CI of OR Lower	Upper	*P* value[a]
Country type						**<0.0001**
Northern Forest	Ref					
Southern Forest	3.17	0.45	23.78	9.78	57.82	<0.01
Central Forest	2.10	0.44	8.14	3.44	19.25	<0.01
Northern Downs	1.46	0.45	4.30	1.78	10.35	<0.01
Year observed						**<0.0001**
2009	Ref					
2010	0.14	0.10	1.15	0.95	1.40	0.15
2011	0.49	0.11	1.62	1.31	2.02	<0.01
Cow-age class						**<0.0001**
First-lactation cows	Ref					
Second-lactation cows	0.22	0.21	1.25	0.82	1.90	0.30
Mature cows (≥4 to ≤8yrs old)	1.20	0.12	3.33	2.65	4.19	<0.01
Aged cows (>8yrs old)	1.18	0.14	3.25	2.45	4.30	<0.01
Estimated period of calving expressed as predicted period when the cow calved						**<0.0001**
Jul-Sep	Ref					
Oct-Nov	1.49	0.06	4.43	3.95	4.97	<0.01
Dec-Jan	2.20	0.07	8.98	7.87	10.25	<0.01
Feb-Mar	1.84	0.08	6.29	5.37	7.38	<0.01
Apr-Jun	1.38	0.11	3.96	3.18	4.94	<0.01
BCS at the pregnancy diagnosis muster						**P=0.0007**
1 to 2	Ref					
2.5	0.45	0.20	1.57	1.06	2.31	0.02
3	0.72	0.19	2.06	1.43	2.96	<0.01
3.5	0.63	0.19	1.88	1.29	2.74	<0.01
4 to 5	0.76	0.20	2.14	1.45	3.14	<0.01
BCS change between pregnancy diagnosis and weaning/branding						**<0.0001**
Maintained or Lost	Ref					
Gained	0.384	0.05	1.47	1.34	1.61	<0.01
Average DMD:CP during wet season						**<0.0001**
≥8:1	Ref					
<8:1	0.36	0.06	1.44	1.27	1.63	<0.01
Average ratio of FP:ME during wet season						**<0.0001**
<500gP:1MJME	Ref					
≥500gP:1MJME	0.96	0.11	2.62	2.12	3.23	<0.01
Interaction: Country type x Cow-age class						**0.005**
Southern Forest: Second-lactation cows	0.51	0.26	1.67	1.00	2.79	0.05
Central Forest: Second-lactation cows	0.71	0.26	2.04	1.22	3.40	<0.01
Northern Downs: Second-lactation cows	0.83	0.25	2.29	1.41	3.72	<0.01
Southern Forest: Mature cows	-0.34	0.17	0.71	0.51	1.00	0.05
Central Forest: Mature cows	-0.23	0.16	0.79	0.58	1.09	0.15
Northern Downs: Mature cows	0.05	0.15	1.05	0.78	1.41	0.74
Southern Forest: Aged cows	-0.23	0.23	0.79	0.50	1.25	0.32
Central Forest: Aged cows	-0.13	0.21	0.88	0.58	1.32	0.54
Northern Downs: Aged cows	0.13	0.18	1.14	0.80	1.62	0.48

Table 7-2. Continued.

Variable	Coefficient	SE	Adjusted OR	95% CI of OR Lower	Upper	*P* value[a]
Interaction: Country type x Body condition score at the pregnancy diagnosis muster						**<0.0001**
Southern Forest: 2.5	-0.46	0.26	0.63	0.38	1.04	0.07
Southern Forest: 3	-0.30	0.24	0.74	0.47	1.17	0.20
Southern Forest: 3.5	-0.07	0.24	0.93	0.58	1.49	0.76
Southern Forest: 4 to 5	0.11	0.25	1.12	0.69	1.81	0.65
Central Forest: 2.5	0.11	0.26	1.12	0.67	1.87	0.66
Central Forest: 3	0.09	0.24	1.09	0.68	1.75	0.71
Central Forest: 3.5	0.39	0.24	1.48	0.92	2.39	0.11
Central Forest: 4 to 5	0.33	0.25	1.39	0.86	2.24	0.18
Northern Downs: 2.5	0.02	0.22	1.02	0.65	1.58	0.95
Northern Downs: 3	0.10	0.21	1.10	0.73	1.66	0.64
Northern Downs: 3.5	0.66	0.21	1.94	1.27	2.95	<0.01
Northern Downs: 4 to 5	0.63	0.22	1.88	1.23	2.89	<0.01
Interaction: Cow-age class x Average FP:ME during wet season						**P<0.0001**
Second-lactation cows: ≥500gP:1MJME	-0.93	0.16	0.40	0.29	0.54	<0.01
Mature cows: ≥500gP:1MJME	-0.86	0.11	0.42	0.34	0.53	<0.01
Aged cows: ≥500gP:1MJME	-0.63	0.15	0.53	0.40	0.71	<0.01
Intercept	-5.54	0.33				**<0.001**
Random effect		Std dev		95% CI Lower	Upper	
Level 2 (property)		1.00		0.82	1.22	
Rho (ICC)		0.23		0.17	0.31	

[a]Bold values are generalised Wald-test *P* values; others are Wald-test *P* values.
Abbreviations: BCS, Body condition score; FP:ME, Ratio of faecal phosphorus to metabolisable energy; DMD:CP, Ratio of dry matter digestibility to dietary crude protein

The fixed part of the final multivariable model fitted the data only partially well with fewer cases of P4M than expected at lower probabilities. The P value for the Hosmer-Lemeshow goodness-of-fit statistic was <0.001, indicating a poor fit. All attempts to improve the fit of the model did not result in changes to the overall significance of covariates or direction of the coefficients for the risk factors. An inspection of covariate values revealed all values to be plausible, and as a result no observations were removed from the dataset.

The predictive abilities of the final model were modest; the area under the receiver operating curve was 0.75 (SE 0.01). Sensitivity was high (>0.90) at very low cut points (<0.2), while specificity was high (>0.90) only at cut points >0.8 (The performance of the final model is further described in Section 7.8.3).

Using the final model predicted mean P4M for risk factors not interacting with other risk factors contained in the model, and for each interaction between risk factors were estimated and are presented as Table 7-3.

Table 7-3. Predicted mean P4M for risk factors and interactions between risk factors. Predicted percentages are based on the estimated marginal means generated from the multivariable logistic regression model and are adjusted for all other factors contained in the model.

Variable	n	Mean P4M (%)	95% CI of Mean	
			Lower	Upper
Year observed				
2009	1,522	35.5	27.5	43.4
2010	13,221	38.8	32.0	45.6
2011	10,327	47.2	40.1	54.3
Estimated period of calving expressed as predicted window when the cow calved				
Jul-Sep	3,619	14.6	10.8	18.3
Oct-Nov	8,755	43.0	35.9	50.2
Dec-Jan	9,195	60.5	53.5	67.5
Feb-Mar	2,722	51.8	44.1	59.4
Apr-Jun	779	40.3	32.1	48.6
BCS change between pregnancy diagnosis and weaning/branding				
Maintained or Lost	19,681	35.9	29.2	42.6
Gained	5,389	45.1	37.8	52.4
Average DMD:CP during wet season				
>8:1	6,884	36.1	29.0	43.2
≤8:1	18,186	44.8	37.8	51.9
Interaction: Country type x BCS at the pregnancy diagnosis muster				
Northern Forest: 1 to 2	318	6.0	2.9	9.2
Northern Forest: 2.5	679	9.2	5.0	13.3
Northern Forest: 3	1,784	11.7	6.9	16.5
Northern Forest: 3.5	1,401	10.8	6.2	15.4
Northern Forest: 4 to 5	1,341	12.1	7.0	17.2
Southern Forest: 1 to 2	431	60.2	45.1	75.2
Southern Forest: 2.5	378	59.8	44.7	74.9
Southern Forest: 3	1,062	69.6	56.9	82.4
Southern Forest: 3.5	1,130	72.5	60.5	84.5
Southern Forest: 4 to 5	1,289	78.3	68.0	88.6
Central Forest: 1 to 2	409	36.4	22.2	50.5
Central Forest: 2.5	460	50.1	35.3	65.0
Central Forest: 3	1,563	56.3	42.2	70.3
Central Forest: 3.5	1,557	61.4	47.9	74.9
Central Forest: 4 to 5	2,170	62.9	49.7	76.2
Northern Downs: 1 to 2	800	26.2	13.8	38.7
Northern Downs: 2.5	896	36.1	21.4	50.8
Northern Downs: 3	2,570	44.7	29.1	60.2
Northern Downs: 3.5	2,294	56.4	40.9	71.9
Northern Downs: 4 to 5	2,538	58.9	43.6	74.2
Interaction: Cow-age class x Average FP:ME during wet season				
First-lactation cows: <500gP:1MJME	2,283	21.4	16.2	26.6
First-lactation cows: ≥500gP:1MJME	2,452	41.7	34.1	49.2
Second-lactation cows: <500gP:1MJME	1,112	36.3	28.6	44.0
Second-lactation cows: ≥500gP:1MJME	1,382	37.1	29.0	45.2
Mature cows: <500gP:1MJME	8,898	44.3	37.0	51.7
Mature cows: ≥500gP:1MJME	5,192	46.8	39.2	54.4
Aged cows:<500gP:1MJME	2,630	45.5	37.6	53.5
Aged cows:≥500gP:1MJME	1,121	53.8	45.4	62.1

Table 7-3. Continued.

Variable	n	Mean P4M (%)	95% CI of Mean	
			Lower	Upper
Interaction: Country type x Cow-age class				
Northern Forest: First-lactation cows	1,344	7.1	3.8	10.3
Northern Forest: Second-lactation cows	203	5.6	2.5	8.8
Northern Forest: Mature cows	3,072	14.1	8.6	19.6
Northern Forest: Aged cows	904	15.2	8.9	21.5
Southern Forest: First-lactation cows	1,035	60.9	46.5	75.3
Southern Forest: Second-lactation cows	647	67.2	53.6	80.8
Southern Forest: Mature cows	2,205	70.6	58.3	82.8
Southern Forest: Aged cows	403	74.6	62.6	86.6
Central Forest: First-lactation cows	1,464	42.6	28.6	56.6
Central Forest: Second-lactation cows	794	54.4	39.8	68.9
Central Forest: Mature cows	3,326	56.0	42.1	69.9
Central Forest: Aged cows	575	60.7	46.5	74.8
Northern Downs: First-lactation cows	892	30.2	16.7	43.6
Northern Downs: Second-lactation cows	850	43.7	27.9	59.5
Northern Downs: Mature cows	5,487	49.5	33.9	65.2
Northern Downs: Aged cows	1,869	53.7	37.9	69.5

Abbreviations: BCS, Body condition score; FP:ME, Ratio of faecal phosphorus to metabolisable energy; DMD:CP, Ratio of dry matter digestibility to dietary crude protein

Generally predicted mean P4M was significantly lower ($P<0.05$) in the Northern Forest compared to that in the other country types, however the effects of country type were dependant on cow-age class (Table 7-2). With the exception of the Southern Forest country type, the lower P4M for first-lactation cows when compared to either mature or aged cows was significant within each of the remaining country types ($P<0.05$). Within the Southern Forest, first-lactation cows performed similarly to second-lactation and mature cows. However, the 13.7 (95% CI, 6.4-21.0%) absolute percentage point higher performance of aged cows was statistically significant, when compared to first-lactation cows (Table 7-3). Within the Northern Forest, first-lactation cows were also found to perform similar to second-lactation cows. However, within both the Central Forest and Northern Downs, the higher P4M of second-lactation cows compared to first-lactation cows was significant ($P<0.05$), 11.8 (95% CI, 5.9-17.7%) and 13.5 (95% CI, 7.6-19.5%) absolute percentage difference, respectively. Aged cows were found to perform similar to mature cows within each country type with the exception of the Northern Downs. Within the Northern Downs, P4M for aged cows was 4.2 (95% CI, 0.6-7.8%) absolute percentage points higher than for mature cows ($P<0.05$).

P4M was lowest for those cows predicted to calve between July and September, and was highest for those cows predicted to calve between December and January. The interaction between estimated period of calving and country type as a predictor of percentage P4M was not able to be assessed in the final model as the widespread use of controlled mating in the Southern and Central Forest resulted in only limited numbers of cows predicted to calve in the periods February to March and April to June .in these country types

Generally, P4M increased as body condition assessed at the pregnancy diagnosis muster increased. However, the effects of body condition on P4M were dependent on country type. Within each country type apart from the Southern Forest, those cows that had a BCS of 1 to 2 (i.e. were in very thin to thin condition) had significantly lower ($P<0.05$) P4M compared to all other categories of body condition (Table 7-2). Within the Southern Forest cows that had a BCS of 1 to 2 had similar P4M to those with a BCS of 2.5. Within all country types, cows that had a BCS of 3.0 at the time of pregnancy diagnosis subsequently had a significantly higher P4M than those cows with a BCS of 2.5. However, within the Northern Forest, those cows with a BCS of 3.5 performed similarly to those with a BCS of 2.5. Also, in the Northern Forest predicted differences in mean percentage P4M between cows with BCS of 3.0, 3.5 and 4 to 5 were not significantly different. However, within the Central Forest and Northern Downs the predicted mean P4M of cows with a BCS of 3.5 was significantly higher than that for cows with a BCS of 3; 5.1 absolute percentage points (95% CI, 0.9-9.4) and 11.7 absolute percentage points (95% CI, 8.4-15.0) higher, respectively (Table 7-3).

Indicators of wet season conditions were associated with P4M with 12.7 percentage point higher ($P<0.001$) expected occurrence of P4M estimated for cows grazing pastures adequate to good quality pasture throughout the wet season (mean DMD:CP ratio <8:1), compared to those cows grazing poorer quality pastures (mean DMD:CP ratio ≥8:1). P4M was associated with changes in body condition between pregnancy diagnosis in the previous annual production cycle and the first annual branding/weaning muster in the following year ($P<0.001$; Table 7-2) with a 9.2 percentage point higher expected occurrence of P4M estimated for those cows graining weight during this period compared to those that either maintained or lost condition (Table 7-3).

Based on the mean wet season ratio of faecal phosphorus to estimated metabolisable energy of the pasture, where risk of phosphorus deficiency was high (<500:1 FP:ME ratio) percentage P4M was estimated at between 0.8-20.3 percentage points lower across cow-age class cohorts compared to where risk of phosphorus deficiency was low (≥500:1 FP:ME ratio; Table 7-3). The associated effect of risk of phosphorus deficiency on P4M was moderated by cow-age class cohort, with the expected occurrence of P4M for first-lactation and aged cows (>8yrs old) at risk of phosphorus deficiency estimated as 20.2 (95% CI, 15.4-25.1; $P<0.001$) and 8.3 (95% CI, 2.2-14.3; $P<0.01$) percentage points lower, when compared to where risk of phosphorus deficiency was low (Table 7-2 and Table 7-3). Similar effects were not estimated for second-lactation and mature cows and were not statistically significant (0.8%, $P=0.78$ and 2.5%, $P=0.16$, respectively).

Population attributable fraction

The estimated population attributable fraction (PAF) for cows which failed to become pregnant within 4 months of calving for all the risk factors retained in the full multivariable model are presented in Table 7-4. Estimates of the proportional reduction in the probability of cows failing to become pregnant within 4 months of calving should be interpreted with some caution as all interaction terms which were contained in the final model were omitted from the model used to estimate PAF.

Table 7-4. Estimated population attributable fraction (PAF) for cows which failed to become pregnant within 4 months of calving for all risk factors retained in the full multivariable model.

Risk Factor	PAF (%)	95% Confidence interval	
		Lower	Upper
Country type	62.5	41.9	75.8
Estimated period of calving	40.4	38.3	42.4
BCS at the pregnancy diagnosis muster	26.2	22.6	29.6
BCS change between pregnancy diagnosis muster and weaning/branding muster	26.0	20.6	31.0
Cow-age class	24.6	18.9	30.0
Average FP:ME during wet season	17.6	11.9	23.0
Year observed	15.2	10.2	19.9
Average DMD:CP during wet season	7.0	3.7	10.1

Abbreviations: BCS, Body condition score; FP:ME, Ratio of faecal phosphorus to metabolisable energy; DMD:CP, Ratio of dry matter digestibility to dietary crude protein

7.4.4 Effects of risk factors not contained in the full multivariable model.

Adjusted for all other predictors in the final model, the risk factor representing cow hip height (<125 cm/≥125 to <140 cm/≥140 cm) was found to be a significant predictor of P4M (P<0.0001). However, the inclusion of the risk factor in the final model resulted in a reduction of seven herds and 8,384 animal production years contributing observations. Overall, percentage P4M decreased with increasing hip height. Mean P4M for cows in the following hip height categories <125 cm, ≥125 to <140 cm and ≥140 cm were predicted to be 47.0% (95% CI, 37.4-56.6%), 40.0% (95% CI, 32.1-47.9%) and 36.2% (95% CI, 28.4-43.9%), respectively.

The inclusion of infectious disease risk factors resulted in a reduction of 17 herds and 13,880 animal production years contributing observations to the modelling and therefore, some caution must be exercised in interpreting results of analyses including these factors. With the exception of management group seroprevalence for BVDV infection, the association between probability of P4M and infectious disease risk factors for *Neospora caninum*, BEF virus infection, *Leptospira hardjo* and *pomona*, and *Campylobacter fetus* subsp. *venerealis* were found to be either or both not statistically significant or biologically implausible. Management group BVDV seroprevlance at the time of pregnancy diagnosis was a significant predictor of P4M (P=0.03). The mean predicted P4M for those cows within groups categorised as having a low (<20%), moderate (≥20 to ≤80%) and high prevalence (>80%) of BVDV seropositive was 57.3% (95% CI, 43.8-70.9%), 43.2% (95% CI, 26.2-60.1%) and 34.3% (95% CI, 17.0-51.6%), respectively. The 23.0 (95% CI, 7.1-39.0) absolute percentage point higher performance of those cows within groups with low BVDV seropositive was significant (P=0.007), when compared to cows within groups of high seropositive.

7.5 Discussion

The data presented is unique and relates to one of few studies that have simultaneously monitored the reproductive performance of commercially managed beef cattle located across major beef cattle breeding regions of northern Australia. After clustering at the herd level, 41.6% (95% CI, 32.3-50.5%) of all cows were observed as being successful for the outcome P4M in the present study and therefore, potentially are able to contribute to the annual calf crop in both the current and subsequent years. The large variation in P4M between country-types with 65.4% (95% CI, 53.1-77.7%), 57.5% (95% CI, 44.8-70.2%), 61.8% (95% CI, 48.1-75.6%), and 16.4% (95% CI, 10.7-22.1%) for the Southern Forest, Central Forest, Northern Downs and Northern Forest, respectively, and demonstrates the dominating effect that regional attributes represented by risk factor country type can have on herd performance. In the present study, the four country types and were likely to differ markedly in terms of their soil-type and fertility, pasture production and nutritive value (Bortolussi *et al.* 2005c). Environmental differences between country types are also probable.

Similar low reproductive rates for cows in northern Australia that were lactating at the time of mating have previously been reported by others (Frisch *et al.* 1987; Burns *et al.* 2010) with the main cause identified as prolonged periods of anoestrus following parturition (Entwistle 1983; Teleni *et al.* 1988). A decreased number of mating opportunities during the mating period of interest is a consequence of an increased period of postpartum anoestrus and therefore, reducing the probability of pregnancy. The main objective of the present study was to identify the important factors associated with P4M. The important predictors of P4M determined in the present study can all be potentially explained through their interaction or associated attributes interaction with the hypothalamic-pituitary-ovarian uterine axis and its impact on post-partum anoestrus.

The summary levels of performance for the present study are consistent with the previously reported generalisation that pregnancy percentages tend to decline in a northerly direction compared to the southern areas of northern Australia (Entwistle 1983). In the present study, only 16.4% (95% CI, 10.7-22.1%) of cows were observed as being successful for P4M within the Northern Forest, which was vastly different to the performance of cows within other country types. Soils within the Northern Forest are largely of poor quality and limited nutrients often limits pasture growth as seasonal rainfall is typically high and pasture growing conditions adequate. As a result of these conditions, pasture quality is low as available nutrients are diluted and pasture quality continually decline over the dry season, limiting animal production (Ash *et al.* 1997).

A monsoonal 'wet' season generally occurs during November through to April, when nearly all of the annual rainfall occurs, and is followed by a 'dry' season during May through to October. In the more southern regions of northern Australia, the chances of rain during the 'dry' months are higher. The variability between years is typical for a wet-dry tropical system and for this reason it has been suggested by others that ecological studies conducted within the northern regions of northern Australia should continue for 6-8 years (Taylor and Tulloch 1985). In the present study, typical of this seasonal variability there were periods of extended dry and large rainfall events causing widespread flooding within some regions. Percentage P4M did vary between years and are thought to reflect the associated year effects not elsewhere accounted for in the model. However, the absence of interactions between other important explanatory factors within the model and season demonstrates the consistency that the other important factors are having across a range of seasons.

Cow-age class was a significant determinant of percentage P4M and its impact was dependant on country type and risk of phosphorus deficiency. Generally, those females that were experiencing lactation for their first or second time had fewer expected occurrences ofP4M when compared to mature and aged cows. These findings are consistent with those previously reported by others (Entwistle 1983; Teleni *et al.* 1988; Schatz and Hearnden 2008; Burns *et al.* 2010). In the present study, the average marginal effect for first or second-lactation cows when compared to mature or aged cows was thought to be greater in those country types typically associated with poorer nutritive value or larger seasonal variability. The poorer performance of first and second lactation females is due to the large nutritional demands of lactation and maternal growth occurring at the same time (Entwistle 1983). The nutritive value of the northern country types of northern Australia are considered less likely to be able to support the nutritional demands of lactating young cattle and potentially resulting in young lactating cows mobilising body reserves to meet their nutritional demands. An association between high mobilisation of body reserves during the peripartum period in primiparous cows and delayed first ovulation after has been established by others (Guedon *et al.* 1999). The association between negative energy balance around the time of calving and delayed post-partum anoestrus is not as evident in multiparous cows. This suggests that primiparous cows display increased sensitivities to nutritional conditions around the time of calving.

The estimated period of calving, estimated using foetal ageing and date of pregnancy diagnosis, was associated with the occurrence of P4M. Percentage P4M was lowest for those cows predicted to calve within the period of July to September and highest for those cows predicted to calve during December to January. The effects of predicted month of calving are thought to be explained by the available nutrition to support lactation and the resumption of cycling after calving. Milk production is lowest during the month of calving and dramatically increases to peak lactation during the second and third month after calving (McCarter *et al.* 1991). At the time of parturition, cows calving in the December to January calving period are likely to be gaining body condition and liveweight as pastures will typically be in adequate supply and of relatively high digestibility and protein content. Additionally, the increased nutritional demands of peak lactation for those cows calving during this period are likely to correspond with pastures of suitable quality to minimise or maintain liveweight and body condition. Those cows calving earlier in the season are likely to be calving in a period of variable rainfall and pasture quality.

The desired calving window by herd managers within Southern Forest often included the July to September calving period. As this preferred calving period does not correspond with maximum expected occurrence of P4M and therefore, increased probability of cows being able to contribute to two consecutive calf crops, other external factors, such as liveweight at the point of weaning or market incentives, may be driving the management of herds such that they calve during this period within this country type.

Body condition as a useful indicator of the energy status of cattle and its association with reproductive performance has been well established and documented (Entwistle 1983; Burns *et al.* 2010). In the present study, the assessment of body condition at the time of pregnancy diagnosis was found to be a stronger predictor than an assessment of body condition at the first annual muster when lactation was assessed and weaning or branding conducted. Others have previously reported this time point as the strongest predictor for risk of cows not becoming pregnant compared other stages of the annual production cycle (Waldner and García Guerra 2013). Additionally, Waldner and García Guerra (2013) hypothesised the strength of assessing body condition at pregnancy diagnosis as a predictor of cows not becoming pregnant, compared to other time points, may be due to less measurement error as cows were restrained within a crush for the purposes of pregnancy diagnosis and an emphasis placed on mustering thus, a larger proportion of cows with complete data.

Body condition and its interaction with country type were found to be significant predictors for occurrence of P4M. Generally, the findings of the present study are consistent with the general agreement that as body condition improves, the expected occurrence of P4M increases. However, for the Northern Forest country type the results varied slightly from those previously reported as differences in the percentage P4M between BCS categories ≥2.5 were not found to be statistically significant. This finding is partially explained by the limited nutritive value of Northern Forest and increased risk of cows losing condition across the wet season, when most cows were expected to calve (McGowan *et al.* 2014). In the present study, the expected occurrence of P4M for cows that either maintained or lost condition throughout the wet season was lower than those cows that gained body condition. Similar associations between cows in negative energy balance around the time of calving and reduced reproductive performance, particularly in primiparous cows have been reported by others (Lalman *et al.* 1997; Waldner and García Guerra 2013). However, these associations have been reported to a lesser extent in multiparous cows.

Others have established that the associated effects of mobilising high levels of body reserves at the time of parturition and diminished reproductive performance is dependent on the body condition of cows at calving. Such that, the effects of mobilising body reserves around the time of calving on reproductive performance were not evident in cows in very good body condition. In contrast, the interaction between body condition score at pregnancy diagnosis and change in body condition throughout the wet season was not found to be a statistically significant predictor of percentage P4M in the present study.

Hip height and its association with P4M can potentially be partially explained by an elevated risk of cows not being able to maintain body condition due to the increased maintenance requirements associated with the larger frame size. Others have reported trends consistent with those in the present study. Even though the finding was not determined as being statistically significant, cows of smaller frame size tended to calve earlier in the breeding season than that for cows of larger frame size in second parity or greater cows (Vargas *et al.* 1999). Suggesting that cows of smaller frame size tended to re-establish a pregnancy earlier in the breeding season than those cows of larger frame size.

The nutritive risk factors of average wet season DMD:CP and risk of phosphorus deficiency impacting on reproductive performance were both found to be associated with the occurrence of P4M. The DMD:CP provides an indicator of the availability of rumen degradable nitrogen to metabolisable energy. In the present study, those cows that were grazing pastures throughout the wet season that averaged a ratio ≤8:1 were observed as having higher expected occurrence of P4M than those cows that where grazing pastures which had a ratio >8:1. This response is potentially explained by cows grazing pastures of increased protein content, relative to available energy, during the peri- and postpartum periods being able to reduce losses in body condition and liveweight during these periods; reducing the time between calving to first oestrus and maximising the number of mating opportunities by four months from calving, increasing the probability of pregnancy.

Phosphorus (P) has been reported as being a key factor of animal production in northern Australia (Miller *et al.* 1990). In the present study, risk of phosphorus deficiency was found to be a statistically significant determinant of percentage P4M and consistent with previous reports, its associated effects were dependent on cow-age class (Miller *et al.* 1997). Insufficient dietary phosphorus intakes have been shown to be associated with reduced voluntary feed intakes and productivity (Wadsworth *et al.* 1990; Dixon *et al.* 2011a). Therefore, it is thought that reductions in fertility are consequences of the energy balances of animals rather than the direct effects of phosphorus (Dixon *et al.* 2011a). As previously established in this paper, the effects of negative energy balance around the time of calving on post-partum anoestrus are heightened in primiparous cows. Likewise, heifers and first-lactation cows are at greatest risk of phosphorus deficiency. In a report by Miller *et al.* (1997), preferential supplementation of heifers and first-lactation cows is recommended as returns are maximised, suggesting that the marginal effects are considered to be highest in these age classes.

It is acknowledged that a shortcoming of the PAF estimates reported in the present study is that interaction terms which were contained in the final model were omitted from the model used to estimate PAF due to computational limitations. In an attempt to explore the effect of omitting interaction terms, PAF estimates from models including dummy coded interaction terms were explored. Moderate changes to the estimated proportional reduction in percent cows that failed to become pregnant within 4 months were evident although, the ranking of risk factors were overall considered comparable. Therefore, presented PAF results should be interpreted with appropriate caution and emphasis is suggested to be placed towards the likely relative importance of different risk factors rather than the PAF estimate.

Population attributable fraction estimates are useful for providing a measure of the relative importance of risk factors, as both the strength of the risk factors' association with the outcome (P4M) and the prevalence of the risk factor within the population is computationally included in its estimation. Based on PAF estimates, top-order determinants of P4M were period of calving and body condition score and body condition score changes around and after calving. In the present study, cow-age class and wet season nutritional risk factors were thought to be of similar importance in determining occurrence of P4M. Country type was determined as the risk factor having the greatest influence on the occurrence of P4M. However, the ability of herd managers to address this risk factor is limited. These analyses suggest that cows within northern Australia should be primarily managed to calve at a desired time of the year and to maintain body condition, which would incorporate practices such as sustainably stocking cattle, the timing of weaning and the provision of adequate nutrients.

As the risk factors representing infectious diseases in the present study were based on monitoring completed in only two of the three annual production years, these risk factors were not eligible to be contained in the final model and some caution needs to be exercised in the interpretation of the results. Nevertheless, in consideration of the risk factors representing infectious diseases with adjustment for all other factors contained in the full multivariable model, the group prevalence of seropositive BVDV infection (Low/Moderate/High) was determined as a statistically significant predictor of P4M (P=0.03) with declining expected occurrence of P4M as levels of the risk factor categorising group prevalence of seropositives for BVDV infection increased. However, the results varied slightly from those previously reported as the previously established association between percentage P4M and prevalence of recent BVDV infection (McGowan *et al.* 1993a) was not determined to be statistically significant ($P > 0.05$). One possible explanation for these results is that due to the sampling methodology used in the present study occurring months after the start of the breeding season, those animals which were infected around the time of breeding have returned antibody reaction levels for BVDV measured using Agar Gel Immunodiffusion (AGID) test consistent with those of an animal that was infected 6-7 months ago, rather than a recently infected animal. If infection of BVDV did not occur at the time of breeding the association between occurrence of P4M and group prevalence of seropositive BVDV infection varies from previously reported studies.

While there are several modelling options to analyse binary data with hierarchical structure, the method with which models computationally handle clustering or grouping of data can be generally categorised as either having a "population-averaged" or "subject-specific" approach.

Random-effect logistic regression models were employed in the present study, generating subject-specific estimates of regression coefficients (odds ratios), and predicted probabilities. Subject-specific models explicitly manage dependencies by incorporating a random effect for each subject in the model (random intercept). Because the estimated effects are adjusted for unmeasured individual differences, they are termed "subject-specific" effects. Odds-ratios estimated from the subject-specific model should be interpreted as representing the change for a single individual or for those individuals with the same random effect estimate.

The population-averaged model describes changes in the population mean given changes in covariates, and does not have a subject-specific focus. Odds-ratios estimated from the population-averaged model should be interpreted as representing the change for an average subject. Population-averaged effect estimates, although not reported, were generated and were found to be numerically very similar to those generated using subject-specific estimators. For the more informed reader equations exist to convert subject-specific effect estimates to population averaged such as those reported by Dohoo *et al.* (2009).

It is acknowledge that the population of properties and herds selected for the study may not be entirely representative of the properties and herds in northern Australia. There is also some potential for selection bias given the large number of herds that were not represented in the model due to incomplete data for one or more risk factors. The herd managers enrolled in the study were a convenience sample and were conducting or prepared to conduct an annual pregnancy diagnosis on all enrolled females, which is not routine practice in many areas of northern Australia. Therefore, the herd managers that participated in the study could be considered the more progressive managers of northern Australia. Additionally, right and interval censoring potentially need acknowledging for this dataset. As a result of the scale of the study, there were some occurrences of herds prematurely concluding their participation in the study and lost identification of cows due to retention failure of NLIS tags. Furthermore, as animals were only mustered biannually there are potentially some instances of misclassification where cows were successful for P4M, however, due to foetal loss were determined as not being pregnant at the pregnancy testing and have been classified as unsuccessful for P4M. Therefore, appropriate caution should be exercised when interpreting results as they may reflect those of a population operating slightly above typical and despite appropriate diligence being placed on recording of data there were some practical limitations of capturing observational data under commercial conditions.

7.6 Conclusions

This study identified several factors as being important for the occurrence of P4M and included age, body condition score at the pregnancy diagnosis muster and changes through the period through to weaning, estimated period of calving, year and country type. Although associations between many of these factors and reproductive performance have been well established, this is likely to be one of the few, if not only, large observational study where in excess of 25,000 cattle have concurrently evaluated these risk factors in north Australian commercial beef herds.

The identified important factors associated with the occurrence of cows being successful for P4M are potentially explained through their impact on post-partum anoestrus and potentially reducing the number of mating opportunities for a cow during the breeding period. The findings of the present study reaffirm the notion that in order to optimise the probability of cows being able to contribute to a calf-crop in consecutive years under commercial conditions in northern Australia, beef breeding production systems should focus on maximising the proportion of cows within a herd calving at the desired time of the year and managing cattle such that they are of good body condition score at the time of calving and are managed such that BCS can be maintained during lactation. These analyses also suggest that any nutritional deficiencies and herd health need to be managed to maximise the reproductive efficiency of cows in northern Australia.

7.7 Contributions by others to the chapter

Mr McCosker was responsible for the management of the data across all country types and capturing the data within the country type of Northern Forrest. Mr McCosker, under the oversight of Dr Perkins, led the analysis and interpretation of the data and was responsible for the writing of the chapter. Data cleaning was overseen by Professor O’Rourke. Professor McGowan led the development of the design in conjunction with Dr Fordyce, Professor O’Rourke and Professor Perkins. Professor McGowan, Dr Fordyce, and Professor O’Rourke have also had a substantial intellectual contribution to the interpretation of the data.

7.8 Additional Material

7.8.1 Univariate screening

Body condition scores measured at different time periods (branding/weaning or pregnancy diagnosis) were highly correlated within individual animals. BCS measured at each time was examined to determine its association with P4M (Table 7-6). Measures of BCS from herd-adjusted logistic regression models with the lowest Akaike's information criteria (AIC) and Bayesian information criteria (BIC) was considered the most informative. A decrease in AIC estimates of 3 are suggested as more informative (Dohoo *et al.* 2009).

Table 7-5. Akaike's and Bayesian information criterion estimates for BCS measured at different time points.

Time BCS measured	AIC	BIC	Lowest
Branding/weaning	21191.7	21238.7	
Pregnancy diagnosis	21150.6	21197.6	***

As FP:ME was a recently developed indicator of the available dietary P and threshold values recently published, there was interest in examining the association of various FP:ME cutpoints with P4M (Table 7-7). The FP:ME cutpoint from herd-adjusted logistic regression models with the lowest Akaike's information criteria (AIC) and Bayesian information criteria (BIC) was considered the most informative.

Table 7-6. Akaike's and Bayesian information criterion estimates for various average FP:ME wet season values.

FP:ME ratio cutpoint	AIC	BIC	Lowest
300:1	35879.9	35904.9	
350:1	35817.6	35842.6	
420:1	35851.6	35876.6	
450:1	35843.2	35868.2	
500:1	35725.9	35750.8	***

Candidate herd management, animal and nutritional and environmental risk factors screened with adjustment for herd-level effects prior to selection of variables for model building are listed in Table 7-7, Table 7-8 and Table 7-9, respectively. Results for only those risk factors with unconditional P values ≤ 0.2 and did not contain ≥40% missing values are presented.

Table 7-7. Results of herd-adjusted logistic regression screening candidate herd management risk factors and P4M risk for all animal production years with valid P4M outcomes, with odds ratio (OR), 95% confidence interval (95% CI) of OR, and P value. Data drawn from 35,902 animal production years involving 26,069 individual cows from 73 herds. Results restricted to only those risk factors with unconditional P values ≤ 0.2.

Variable	Raw observations		OR	95% CI of OR		p-value
	Empty (n)	Pregnant (n)		Lower	Upper	
Property management experience of manager						P=0.04
<10 years	10,220	9,353	Ref			
≥10 to <20 years	1,596	2,194	2.00	0.76	5.31	0.16
≥20 years	5,090	7,449	2.38	1.18	4.80	0.02
Reported size of the herd						P=0.002
≥1000	4,518	7,847	Ref			
<1000	9,598	10,142	2.82	1.47	5.42	<0.01
Average size of management group at pregnancy diagnosis						P=0.002
>400	6,784	6,842	Ref			
<150	1,525	2,726	4.36	1.69	11.26	<0.01
150-400	8,597	9,428	1.21	0.54	2.74	0.64
Bull selection policy						P=0.003
Little	7,230	6,859	Ref			
Some	2,839	4,038	4.30	1.81	10.26	<0.01
Most	6,269	7,554	2.57	1.22	5.45	0.01
Annual bull management policy						P=0.03
Little	6,787	6,092	Ref			
Some	3,377	4,838	2.34	0.94	5.83	0.07
Most	6,174	7,521	3.13	1.33	7.36	<0.01
Culling rate of breeding females						P=0.13
<10%	4,479	4,167	Ref			
10-<15%	4,276	7,611	2.48	1.03	5.97	0.04
≥15%	8,151	7,218	1.33	0.64	2.78	0.43
Culling age of breeding females						P=0.07
Not practiced	2,045	1,723	Ref			
≤10 years	11,879	13,505	2.69	0.98	7.40	0.06
>10 years	1,373	1,849	3.85	1.17	12.69	0.03
Mating management						P<0.0001
>7m without seg	3,988	1,317	Ref			
≤3m	4,109	7,392	10.13	5.05	20.29	<0.01
4-7m	6,285	5,959	4.65	2.41	8.97	<0.01
>7m with seg	2,455	4,235	3.83	0.96	15.18	0.06

Table 7-7. Continued.

Variable	Raw observations Empty (n)	Pregnant (n)	OR	95% CI of OR Lower	Upper	p-value
Botulinium property vaccination policy						P=0.001
Vaccinated	11,195	10,439	Ref			
Not vaccinated	5,303	7,999	3.01	1.61	5.63	<0.01
Leptospirosis property vaccination policy						P=0.001
Not vaccinated	5,303	7,999	Ref			
Vaccinated	11,195	10,439	3.40	1.64	6.28	<0.01
Bulls vaccinated for BEF						P<0.0001
Not vaccinated	13,390	12,370	Ref			
Vaccinated	3,108	6,068	4.64	2.38	9.02	<0.01

Table 7-8. Results of herd-adjusted logistic regression screening of candidate nutritional and environmental risk factors and P4M risk for all animal production years with valid P4M outcomes, with odds ratio (OR), 95% confidence interval (95% CI) of OR, and P value. Data drawn from 35,902 animal production years involving 26,069 individual cows from 73 herds. Results restricted to only those risk factors with unconditional P values ≤ 0.2.

Variable	Raw observations Empty (n)	Pregnant (n)	OR	95% CI of OR Lower	Upper	p-value
Country type						P<0.0001
Northern Forest	7,358	2,269	Ref			
Southern Forest	2,439	4,221	9.92	5.58	17.62	<0.01
Central Forest	2,639	4,371	9.50	5.18	17.42	<0.01
Northern Downs	4,470	8,135	8.03	4.19	15.40	<0.01
Year observed						P<0.0001
2009	1158	583	Ref			
2010	8,997	8,823	2.55	2.25	2.87	<0.01
2011	6,751	9,590	4.15	3.67	4.69	<0.01
Minimum dry season biomass						P<0.0001
<2000 kg/ha	8,135	6,224	Ref			
≥2000 kg/ha	6,448	10,842	1.68	1.52	1.87	<0.01
Average dry season dietary crude protein						P=0.07
≥7%	2,620	4,834	Ref			
<7%	12,811	13,412	1.07	0.99	1.16	0.07
Average dry season dry matter digestibility						P<0.0001
≥55%	2,468	4,714	Ref			
<55%	12,963	13,532	1.26	0.01	1.37	<0.01
Average ratio of dry matter digestibility to dietary crude protein during dry season						P<0.0001
<8:1	4,295	7,478	Ref			
≥8:1	11,136	10,768	1.83	1.66	2.03	<0.01
Dry season nitrogen status						P<0.0001
Adequate	2,513	3,560	Ref			
Deficient & no supplement	2,204	4,502	1.21	1.03	1.42	0.02
Deficient & supplement	8,494	5,982	2.42	2.12	2.76	<0.01
Management	2,455	4,235	1.52	0.24	9.67	0.66
Provision of supplemental nitrogen						P<0.0001
Provided	12,906	11,806	Ref			
Not provided	4,000	7,190	3.18	1.70	5.97	<0.01
Wet season onset						P<0.0001
Late	326	100	Ref			
Early	8,705	11,714	5.44	4.07	7.28	<0.01
Normal	7,701	6,794	3.52	2.63	4.72	<0.01

Table 7-8. Continued.

Variable	Raw observations Empty (n)	Pregnant (n)	OR	95% CI of OR Lower	Upper	p-value
Wet season duration						P<0.0001
Normal	9,766	6,291	Ref			
Short	1,541	2,668	1.78	1.60	1.98	<0.01
Long	5,425	9,649	1.90	1.78	2.03	<0.01
Wet season description						P<0.0001
Short and Late	213	340	Ref			
Normal and Short	1,063	2,372	7.14	5.25	9.71	<0.01
Normal and Normal	10,248	8,887	2.96	2.21	3.97	<0.01
Early and Normal	1,258	1,955	4.26	3.14	5.79	<0.01
Early and Long	3,950	5,054	6.20	4.63	8.29	<0.01
Average wet season dietary crude protein						P=0.86
<7%	3,413	1,659	Ref			
≥7%	10,199	15,247	1.02	0.84	1.23	0.86
Average wet season dry matter digestibility						
<55%	2,696	2,259	Ref			
≥55%	10,916	14,647	1.56	1.37	1.77	<0.01
Average ratio of dry matter digestibility to dietary crude protein during wet season						P=0.004
<8:1	9,117	12,924	Ref			
≥8:1	4,495	3,982	1.13	1.04	1.23	<0.01
Average ratio of Faecal phosphorus to Metabolisable Energy during wet season						P<0.0001
<500 gP : 1 MJ ME	9,386	9,886	Ref			
≥500 gP : 1 MJ ME	4,226	7,020	1.73	1.59	1.89	<0.01
Wet season phosphorus status						P<0.0001
<500:1 & supplement	6,820	6,683				
<500:1 & no supplement	2,566	3,203	1.29	1.09	1.54	<0.01
≥500:1	4,226	7,020	1.99	1.75	2.26	<0.01
Provision of supplemental phosphorus						P=0.08
Provided	12,906	11,806	Ref			
Not provided	4,000	7,190	1.83	0.94	3.54	0.08
Average THI during month of calving						P<0.0001
<72	1,218	1,349	Ref			
72-78	4,557	5,321	2.63	2.34	2.95	<0.01
≥79	11,131	12,326	5.93	5.23	6.73	<0.01
No days ≥72 during month of calving						P<0.0001
≤10 days	721	764	Ref			
≥11 days	16,185	18,232	3.31	2.88	3.81	<0.01
No days ≥79 during month of calving						P<0.0001
≤14 days	5,811	6,466	Ref			
≥15 days	11,095	12,530	2.68	2.49	2.88	<0.01
No days ≥33oC during month of calving						P<0.0001
<10 days	7,354	8,112	Ref			
≥10 days	9,552	10,884	1.62	1.52	1.74	<0.01
No days ≥40oC during month of calving						P<0.0001
≥14 days	682	468	Ref			
<14 days	16,224	18,528	1.92	1.65	2.23	<0.01
Proportion paddock <2.5km of water at the time of calving						P<0.0001
<39%	2,421	2,526	Ref			
39-68%	2,074	2,690	0.98	0.88	1.09	0.69
>68-89%	1,765	3,114	1.26	1.10	1.44	<0.01
>89-<100%	2,194	2,789	1.44	1.20	1.73	<0.01
100%	3,619	5,752	2.64	2.12	3.28	<0.01

Table 7-9. Results of herd-adjusted logistic regression screening candidate animal risk factors and P4M risk for all animal production years with valid P4M outcomes, with odds ratio (OR), 95% confidence interval (95% CI) of OR, and P value. Data drawn from 35,902 animal production years involving 26,069 individual cows from 73 herds. Results restricted to only those risk factors with unconditional P values ≤ 0.2.

Variable	Raw observations		OR	95% CI of OR		p-value
	Empty (n)	Pregnant (n)		Lower	Upper	
Genotype						P<0.0001
≥75% Bos indicus	4,611	2,393	Ref			
<75% Bos indicus	12,295	16,603	4.22	2.29	7.77	<0.01
Cow-age class						P<0.0001
First-lactation cows	3,880	2,108	Ref			
Second-lactation cows	1,359	1,856	2.26	2.05	2.49	<0.01
Mature cows	9,090	11,922	3.08	2.86	3.31	<0.01
Aged cows	2,577	3,110	3.08	2.81	3.38	<0.01
Hip Height (cm)						P<0.0001
>125-140	487	597	Ref			
≤125	7,750	8,004	1.39	1.17	1.66	<0.01
≥140	2,548	3,093	1.16	1.07	1.25	<0.01
Estimated period of calving expressed as predicted window when the cow calved						P<0.0001
Jul-Sep	2,820	1,868	Ref			
Oct-Nov	5,475	6,653	4.90	4.45	5.40	<0.01
Dec-Jan	5,096	7,998	9.39	8.44	10.45	<0.01
Feb-Mar	2,308	1,841	6.47	5.70	7.34	<0.01
Apr-Jun	1,207	636	3.33	2.86	3.87	<0.01
Body condition score at the pregnancy diagnosis muster						P<0.0001
1 to 2	1,972	1,653	Ref			
2.5	5,328	5,511	1.27	1.13	1.43	<0.01
3	1,789	1,140	1.47	1.32	1.63	<0.01
3.5	3,437	5,192	1.59	1.43	1.76	<0.01
4 to 5	4,209	5,258	1.29	1.16	1.43	<0.01
Body condition score at the weaning/branding muster						P<0.0001
1 to 2	3,138	889	Ref			
2.5	3,768	2,366	1.96	1.77	2.17	<0.01
3	4,509	6,250	3.39	3.07	3.75	<0.01
3.5	1,897	4,046	4.66	4.18	5.20	<0.01
4 to 5	844	2,277	4.68	4.11	5.34	<0.01
Body condition score change between pregnancy diagnosis and weaning/branding						P<0.0001
Maintained or Lost	11,234	11,792	Ref			
Gained	2,849	4,015	1.28	1.20	1.36	<0.01
Liveweight at the pregnancy diagnosis muster						P<0.0001
<420 kg	5,643	3,405	Ref			
420-<500	4,237	5,415	1.55	1.44	1.66	<0.01
≥500	2,402	5,040	1.81	1.67	1.97	<0.01

7.8.2 Model performance

Distributions of observed and expected frequencies differed significantly (P<0.001) when expected frequencies were based on the fixed part of the final model, suggesting that the fixed part of the model was poorly calibrated. The fixed part of final multivariable model fitted the data only partially well with more than expected cases of P4M at lower probabilities (Table 7-10).

Table 7-10. Observed (Obs) and expected (Exp) frequencies by decile of risk using estimated probabilities from the fixed part of the final model of P4M.

		Pregnant within four months of calving whilst lactating				
		Not pregnant		Pregnant		
Decile	Probability	Obs	Exp	Obs	Exp	Total
1	0.094	2,175	2,273	333	235	2,508
2	0.198	1,822	2,009	684	497	2,506
3	0.284	1,666	1,796	843	713	2,509
4	0.435	1,233	1,457	1345	1121	2,578
5	0.574	989	1,071	1523	1441	2,512
6	0.647	769	900	1777	1646	2,546
7	0.687	875	748	1515	1642	2,390
8	0.744	674	671	1947	1950	2,621
9	0.781	547	531	1884	1900	2,431
10	0.842	435	390	2034	2079	2,469

There were 3,915 standardised residuals ($\Delta\beta$) greater than 3 or less than –3, equivalent to 15.6% of all observations in the dataset. The highest observed standardised residual was 14.16. Elevated $\Delta\chi2$ statistics (greater than 27) were reported for 275 cases and no common covariate patterns were found. The final analysis was repeated after removing the 275 cases with the largest $\Delta\chi2$ statistics which altered 17 of the 44 coefficients by more than 10%. The overall significance of covariates and direction of the coefficients for the risk factors was similar for both models. An inspection of covariate coefficients revealed all values to be plausible, and as a result no observations were removed from the dataset (Dohoo *et al.* 2009).

The final model had an acceptable ability to discriminate between those cows that were positive for P4M to those that were not, with 68.9% correct predictions. Using a probability cutpoint of 0.597, determined by inspection of a graph of the sensitivity and specificity versus the probability cut points (Figure 7-1), classification statistics were calculated and are presented in Table 7-11. Sensitivity was high at low probability cut points (<0.2) while, specificity was high at probability cut points >0.8 (Figure 7-1). The area under the receiver operating characteristic curve was estimated as 0.75 (95% CI, 0.74-0.75) (Figure 7-2).

Table 7-11. Classification for the final model based on the probability cutpoint 0.597.

Observed P4M	Classified (predicted) status		Total
	pr(P4M)<0.597	pr(P4M)≥0.597	
0	7,664	3,521	11,185
1	4,287	9,598	13,885
Total	11,951	13,119	25,070

Sensitivity	69.1%
Specificity	68.5%
Positive Predictive value	73.2%
Negative Predictive value	64.1%
Percent correct predictions	68.9%

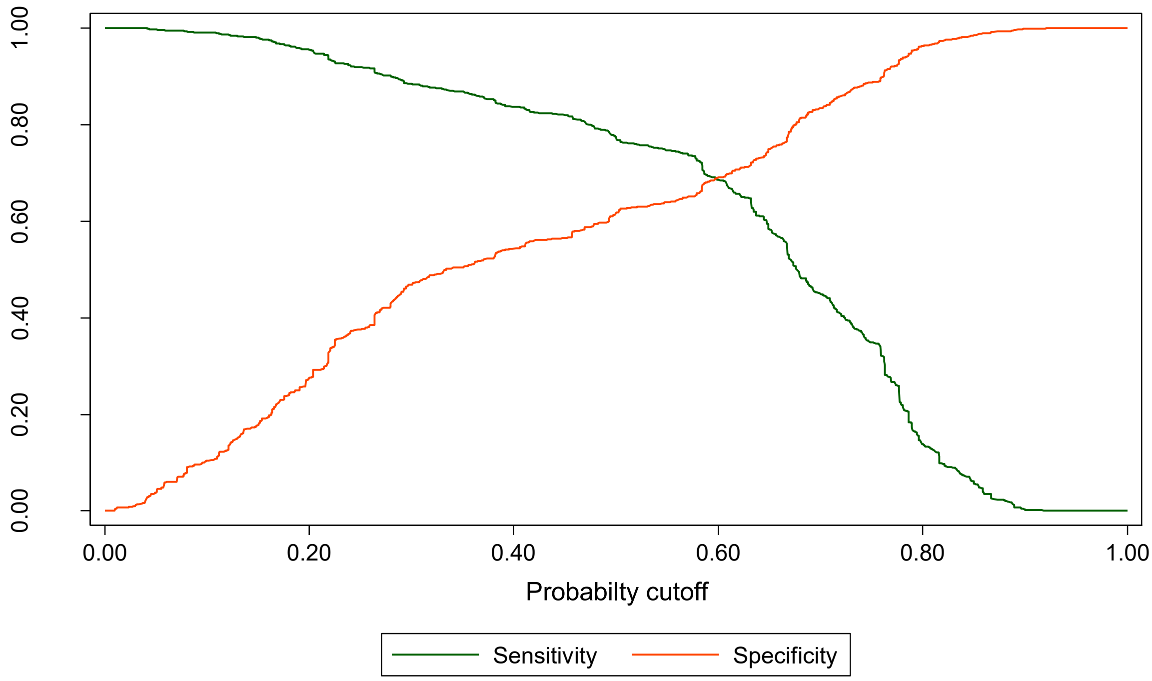

Figure 7-1. Sensitivity and specificity of the final model.

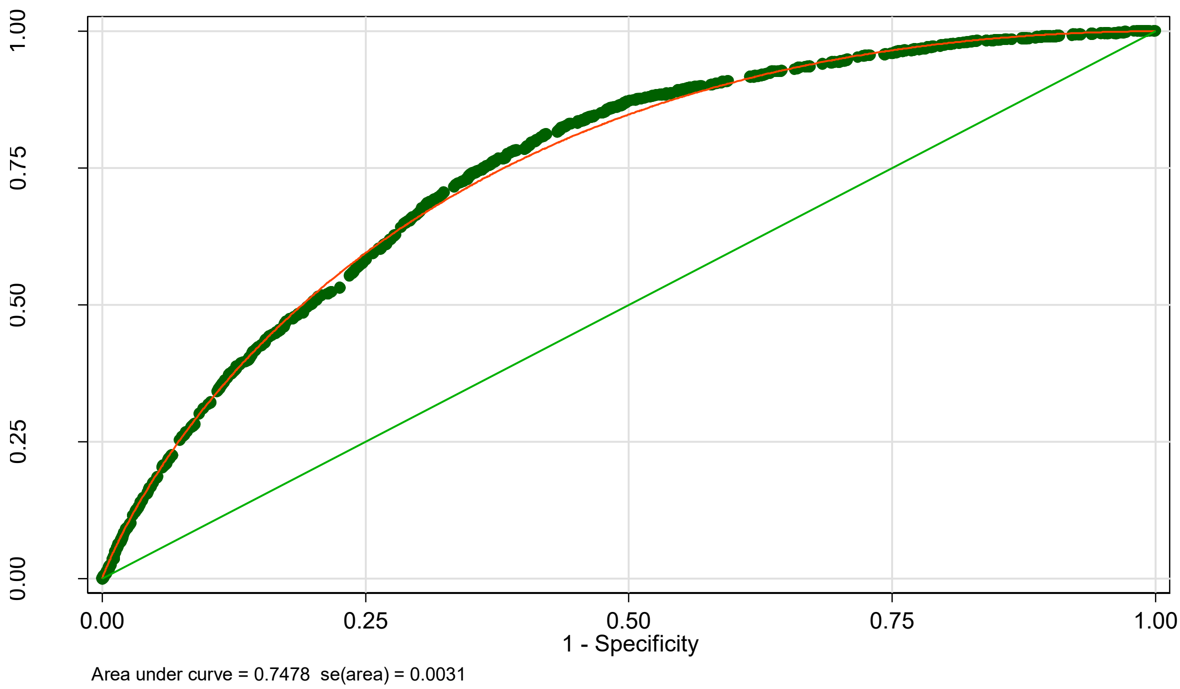

Figure 7-2. Area under the receiver operating characteristic curve using only the fixed part of the final model.

7.8.3 Sources of variation

The final model 'explained' 27.0% of the outcome variance, 17.0% of the variance was unexplained at the herd-level and 56.0% was unexplained at the animal production year-level. The random (herd level) intercept variance reduced by 49.7%, from 1.99 in the null model to 1.00 in the full model. This suggests that the most important factors in the study herds for the proportion of the herd P4M were accounted for by the fitted variables.

However, the intra-class correlation coefficient was 0.38 in the null model, which reduced to 0.23 in the full model. Suggesting that the proportion of the overall residual variation that is attributable to property level effects, which is not explained by the fitted variables, is still relatively large. Improvement to the modelling of probability of cows successfully achieving P4M could result from further refinement of the considered in the final model or addition of further variables.

Chapter 8 Risk factors affecting the occurrence of non-pregnancy in commercial beef cattle in northern Australia

8.1 Abstract

A prospective population-based epidemiological study was conducted between 2007 and 2011 to determine the major factors influencing the occurrence of cows failing to become pregnant within an approximate 12 month reproductive cycle (non-pregnancy) in northern Australian beef breeding cows. Using data representing 73 herds and 62,323 animal production cycles associations between non-pregnancy and approximately eighty candidate risk factors representing property-, management group- and cow-level characteristics and attributes were considered. The analysis of data was based on four broad country types derived from estimates by the collaborating herd manager of annual growth of yearling steers grazing similar pastures to those of heifers and cows in the study. An estimate of overall prevalence of non-pregnancy was 20.4% of cows per annual production cycle with a disproportionate number within the Northern Forest (57%). The prevalence of non-pregnancy for Northern Forest, Northern Downs, Central Forest and Southern Forest was estimated at 32.1%, 17.1%, 16.0% and 13.2%, respectively.

The fixed effects contained in the selected model reaffirmed the dominating effects of reproductive outcome in the previous annual production cycle (including time of calving) and nutritional parameters including: BCS measured at the branding/weaning muster, wet season pasture protein, available metabolisable energy derived from pasture and risk of phosphorus deficiency. The final multivariable model explained 28.1% of the variance at the property level that had been estimated using an intercept only model.

The occurrence of non-pregnancy generally increased as time of calving increased with the expected occurrence of non-pregnancy, expressed as a percentage, ranged between 8-15% across cow-age cohorts for cows that calved between July to September, compared to 25-37% for those that calved between February to March. The expected occurrence of non-pregnancy was typically 5-12 percentage points higher for first-lactation cows and not dissimilar between mature and aged cows.

Season had a consistent effect on the non-pregnancy while, the association between expected occurrence of non-pregnancy and risk of phosphorus deficiency was dependent on country type and average protein content of wet season pasture. A 13.2 percentage points higher expected occurrence of non-pregnancy was estimated in the Northern Forest where the risk of phosphorus deficiency was high (average faecal phosphorus to metabolisable energy ratio <500:1 during the wet season) compared to where the risk of phosphorus deficiency was low (faecal phosphorus to metabolisable

energy ratio ≥500). However, similar association were not statistically significant in other country types. A 10.2 percentage point higher expected occurrence of non-pregnancy was estimated for cows that grazed dry season pastures averaging <55% dry matter digestibility, compared to those that grazed pastures ≥55% DMD.

The major conclusion from this research is that several risk factors have large and additive effects on non-pregnancy in northern Australia. It is suggested that herd managers should primarily direct resources and investment towards sustainable pasture management practices supported by appropriate nutritional management and weaning to allow the majority of cows within breeding herds to readily conceive early in the mating period to ensure adequate future levels of reproductive performance.

8.2 Introduction

Breeding is a major production activity for most beef cattle properties in northern Australia (Bortolussi *et al.* 2005b). Therefore, reproductive performance is an important driver of the profitability and thus, viability of beef breeding operations. Reproduction in northern Australia is typically low with post-partum anoestrus being the main factor identified to limit production (Entwistle 1983).

Branding rates in northern Australia were recently reported as averaging 71 percent for the 10 years ending in 2011-12 (Martin *et al.* 2013). However, Australian Bureau of Agricultural and Resource Economics and Sciences' annual Australian Agricultural and Grazing Industries Survey data suggests differences in branding rates in the order of 20-30 percentage points between regions (Gleeson *et al.* 2012). Reproductive performance for important beef cattle production areas of northern Australia has previously been reviewed with large variation and overlap between regions highlighted by Entwistle (1983); Holroyd and O'Rourke (1989); Hasker (2000) and Burns *et al.* (2010). This substantial variation between herds, highlights that if causal factors of this variation were identified, understood and quantified, targeted remedial management may moderate their impacts to increase reproductive performance.

A number of property, herd and animal-level factors have been shown to influence annual pregnancy percentages of beef breeding herds and include known factors such as: age, nutrition, time and duration of lactation and time of calving (Hasker 2000). The impact of most of these factors have been established in studies that have either not partitioned or controlled the effects of other extraneous factors and/or were conducted in non-commercial situations such as research stations. Currently, there are no known large observational studies that have simultaneously assessed the relative importance of these factors in commercial beef herds of northern Australia. Therefore, it is not known if magnitude of effects drawn from the results of the more intensive controlled studies can be reasonably applied to the broader commercial beef breeding population of northern Australia.

The present study is part of a larger prospective population-based epidemiological study with the major aim of measuring and identifying the important determinants of productivity in north Australian commercial beef breeding herds. The aim of this study was to determine the major factors influencing the risk of non-pregnancy in commercial north Australian beef cows and to quantify the impact of the factors that were determined as being important.

8.3 Materials and methods

8.3.1 Study Design and Population

An observational study was conducted between 2009 and 2011 in commercial beef breeding herds of northern Australia. Seventy-eight sites across the major beef producing regions of Queensland, Northern Territory and Western Australia participated in the study.

The present study is part of a larger prospective population-based epidemiological study aimed at measuring and identifying important determinants of reproductive productivity in north Australian commercial beef herds. Collaborating beef businesses were identified using a non-random process (McGowan *et al.* 2014) aimed at enrolling representative herds where good cooperation was highly-likely to be achieved. Each participating herd usually enrolled two groups of females, which usually represented the two age classes of first-lactation, and mature and aged cows. It should be noted that heifer groups were not represented in this study as determinants either directly impacting on or intervening factors modifying their effect on non-pregnancy in heifers is likely to largely different to those of cows eg. puberty. Management groups enrolled in the study were mostly between 100 and 500 cows in size. In groups of females larger than 500 cows, a representative subset of 300 cows was enrolled.

8.3.2 Location of herds

The analysis of data was based on four country types used to describe the production potential of the grazing land utilised during study. Properties were assigned to one of four country types following a subjective assessment of the production potential of the grazing land and cross-referencing with pasture and vegetation descriptions reported by the herd managers. Properties with forested land-types with fertile soils in the central and south-east sub-tropical regions of Queensland were differentiated by being outside (Southern Forest) and within (Central Forest) the northern Brigalow belt. In the northern tropical areas of Queensland, Northern Territory and Western Australia, properties with land types that were predominantly large treeless black soils plains (Northern Downs) were differentiated from those with forested land-types and low fertility soils (Northern Forest).

8.3.3 Potential risk factors assessed

Cows were individually identified using an National Livestock Identification System (NLIS; www.nlis.com.au) tags. NLIS tags were replaced if the tag was missing or was present but could not be read. In the event of a NLIS tag being replaced, data linkages to previous performance records were often able to be established as study animals were individually identifiable by a separate visual identification tag.

Candidate resource (eg. property area, herd size, average rainfall) and herd management factors (eg. culling and selection policies, provision of supplements, weaning and vaccination policies) were derived from data obtained from a face-to-face survey of cooperating herd managers at the commencement of the study. Further explanation of these factors and their prevalence within the study population are presented in this thesis as Chapters 4 and 6. In northern parts of northern Australia cows are mostly continuously mated, defined as >7 months deliberate exposure to bulls, and sometimes segregated into management groups based on expected times of lactation. In southern areas where suitable bull control is often achieved 3 to 7 months seasonal mating was common.

Continued nutritional monitoring of study herds were based on estimates of dietary protein and dry matter digestibility determined by faecal near infrared spectroscopy (F.NIRS) (Dixon and Coates 2005) and dietary P status using wet chemistry faecal phosphorus (FP) analysis (Jackson *et al.* 2012) (samples collected in January, March, May, August November), and pasture assessments by the collaborators (Chilcott *et al.* 2003). Using the GPS location of a paddock or homestead daily interpolated environmental data (such as temperature and rainfall) was obtained from the Australian Bureau of Meteorology (https://www.longpaddock.qld.gov.au/silo/datadrill/index.php). Paddock factors (paddock area, distances to water) were calculated using the ArcMap GIS program.

Performance and explanatory data were recorded twice a year for each individual cow, at the main branding or weaning muster and again at the pregnancy diagnosis (PD) muster (approximately 4 to 5 months later). At a study animal's first muster information on estimated percentage of *Bos indicus*, year brand and hip height (Fordyce *et al.* 2013a) were captured. At each muster, body condition score (1-5 scale) (Gaden *et al.* 2005), lactation status were assessed and recorded, and wherever possible liveweight recorded.

Pregnancy was identified via transrectal palpation annually by an accredited veterinarian (National Pregnancy Diagnosis Scheme, Australian Cattle Veterinarians) for all cows at the PD muster and if pregnant foetal age estimated. Conceptions estimated to have occurred after September 1 were attributed to the next annual production cycle. This matched usual peak calving in November, few calves born in the middle of the year, thus one production cycle being that where calves are born in a winter to autumn period, and mostly weaned at 6-7 months of age in the calendar year following peak calving. In commercial systems, calves are usually branded with the last digit of their calendar year of weaning.

8.3.4 Deriving the outcome non-pregnancy

Annual pregnancy status was defined as a single record for each annual period and each female that was enrolled in the study and exposed to mating in a given year. Cows were recorded as non-pregnant if they failed to be determined as pregnant within an annual production cycle. An annual production cycle was the period from the end of a pregnancy diagnosis muster to the end of the pregnancy diagnosis muster in the following year, which were conducted approximately 12 months apart. There were occasions where non-pregnancy for animals was misclassified and retrospectively ascribed as pregnant during data checking procedures, which included cross referencing pregnancy status with subsequent lactation. The estimated month of calving was based on results of foetal ageing following transrectal palpation of the reproductive tract at the date of the pregnancy diagnosis and projected forward using an assumed gestation length of 287 days (Casas *et al.* 2011).

8.3.5 Data management and statistical analyses

At each site, animal data were collected at the time of mustering using commercially available automated data collection systems, such as AgInfoLink's BeefLink™ program, that captured data against individual electronic animal IDs and interfaced with liveweight scale indicators. Records were managed using a relational database (Microsoft Access 2010 for Windows; Microsoft Corporation, Washington, USA) and a spreadsheet system (Microsoft Excel 2010 for Windows; Microsoft Corporation, Washington, USA). All statistical analyses were performed using StataIC® (versions 11 and 12 for windows; Stata Corporation, Texas, USA) with one animal's annual production as the unit of analysis.

Screening of risk factors for inclusion in the multivariable model building process was based on associations between potential risk factors and non-pregnancy using a random-effects logistic regression model with Stata's -xtlogit- command, fitting herd as a random effect. The overall significance of risk factors were assessed using Wald-test P values. Risk factors were retained for consideration in the multivariable model building process if their association with the outcome was significant at $P \leq 0.20$ (Dohoo *et al.* 2009).

The assumption of linearity of continuous variables in the logit were evaluated by inspecting partial residual graphs following herd-adjusted logistic regression models fitting the continuous variables as the main effect of non-pregnancy using Stata's –lpartr- command (Hilbe 2009). Continuous variables that appeared to fail the assumption of linearity were categorised into two or more categories. Wherever possible, continuous variables were categorised using established threshold values. However, in some cases, where these were not found to be discriminatory, cut points were determined by changes in the slope of cubic splines fitted to partial residual plots.

Examination of pairwise Spearman correlations were used to identify pairs of risk factors that were highly correlated ($r \geq 0.90$) (Dohoo *et al.* 2009). Where pairs of risk factors were highly correlated, one risk factor was selected for inclusion in the multivariable model building process on the basis of biological plausibility, fewer missing values and Akaike's and Schwarz's Bayesian information criteria estimates. Putative risk factors that had an excessive amount (≥ 40%) of missing values were not considered for inclusion in the multivariable model building process.

A multivariable model was built using a backwards elimination process. Commencing with all significant ($P \leq 0.20$) risk factors on screening being added to a starting model, non-significant variables with the highest p-value were dropped one at a time. This process was continued until only significant ($P \leq 0.05$) variables remained in an interim model. With the exception of those variables with a high degree of missing values, all risk factors previously eliminated during the model building process were again reconsidered, one at a time, for inclusion into the interim model. The predictor -country type- was forced into all interim models due to specific interest in the effects of region that were being represented by -country type-. An appraisal of effects of potential confounding variables was completed by individually including each variable into the candidate model and assessing changes in the measure of association for statistically significant variables. Confounding was considered important when odds ratios for statistically significant variables changed by >20-30% ((Dohoo *et al.* 2009) and the variable was included in the final main effects model. All potential interactions between pairs of risk factors remaining in the interim model were considered one at a time and were retained in the final model if their association was significant ($P \leq 0.05$) and their effects biologically plausible.

The fit of the multivariable model was evaluated by assessing the fit of the model and identifying observations that did not fit the model well (outliers) or having an undue influence on the model. The overall goodness-of-fit of multivariable model was assessed using Hosmer-Lemshow goodness-of-fit tables and statistics (Hosmer *et al.* 2013). Outliers were identified by an analysis of the residuals and were omitted if they were found to be erroneous or having an undue effect on the model.

Following fitting the final multivariable model, average marginal effects of risk factors were computed using Stata's -margins- postestimation command. Differences between estimated marginal means across levels of each risk factor or interaction term were estimated and statistically compared using nonlinear combinations of estimators and pairwise comparisons, respectively.

8.3.6 Population attributable fractions

The population attributable fraction is a statistic used to compare the relative importance of risk factors and represents the theoretical proportional reduction in negative outcomes that would be achieved by eliminating the exposure(s) of interest from the population while distributions of other risk factors in the population remained unchanged. Its estimation therefore is dependent on the prevalence and the strength of association for the risk factor(s) of interest. Using a logistic regression model fitting only main explanatory factors that were contained in the multivariable model, the population attributable fractions were estimated using Newson (2010) Stata command -punafcc-.

8.3.7 Ethical clearance

Ethical clearance was obtained from the University Animal Ethics Committee (Production and Companion Animal), The University of Queensland.

8.4 Results

8.4.1 Description of study population

The starting dataset contained observations from 73 herds relating to 62,323 animal production years from cows deliberately mated to bulls with valid records for pregnancy status in the current year. An average of 1.3 annual production cycles that the outcome of non-pregnancy could be ascribed to were contributed by each individual cow.

Using a null model, the population-averaged prevalence of non-pregnancy was estimated as 20.4% (95% CI, 17.3-23.6%) of cows per production year. Most of the 14,883 observed cases of non-pregnancy were within the Northern Forest (57%) or Northern Downs (22%). The average expected occurrence of non-pregnancy for cows in Northern Forest, Northern Downs, Central Forest and Southern Forest was estimated as 32.1% (95% CI, 26.7-37.6%), 17.1% (95% CI, 11.7-22.6%), 16.0% (95% CI, 11.4-20.7%) and 13.2% (95% CI, 9.7-16.8%), respectively. The percentage of variation in non-pregnancy explained by differences at the herd level in the null model was estimated to be 23.9%.

8.4.2 Herd-adjusted univariable associations

The candidate risk factors that were considered during univariate screening and progressed into the multivariable modelling process are presented in Table 8-1 (Results of herd-adjusted logistic regression models to screen candidate risk factors by including each candidate risk factor as a single main effect term is presented as additional material in Section 8.8.1). Information relating to an additional eight candidate risk factors was accessible for potential inclusion in the multivariate modelling process. Two risk factors (hip height; average change in liveweight for management group between PD muster in the previous year and branding/weaning muster of the current year) did not progress into the multivariable modelling process due to having ≥40% incomplete records.

A further six risk factors were not considered in the multivariable model building process as they were not significant using the liberal p-value of 0.2 (Dohoo *et al.* 2009) and included: number of days exceeding 40°C during the estimated month of calving in the previous production cycle; average dietary CP content during the wet season; provision of supplemental phosphorus; mustering inefficiency; age cows are routinely culled based on age; and property pestivirus vaccination policy.

Table 8-1. List of cow- and herd-level risk factors for cows at the risk of non-pregnancy that were considered during unconditional assessment and were considered in the multivariable model building process.

Risk Factor	
Herd management	
Genotype	Culling rate of breeding females
Property management experience of manager Reported size of the herd	Culling age of breeding females
Average size of management group at pregnancy diagnosis	Mating management
Bull:Female ratio	Botulinium property vaccination policy
Bull selection policy	Leptospirosis property vaccination policy
	Bulls vaccinated for BEF
	Annual bull management policy
Environment	
Year observed	Cumulative number of days temperature humidity index exceeded 71 during month of calving
Wet season onset	Cumulative number of days temperature humidity index exceeded 79 during month of calving
Wet season duration	Average temperature humidity index during month of calving
Cumulative number of days maximum temperature exceeded 32°C during month of calving	
Average temperature humidity index during month of calving	
Nutrition	
Minimum dry season biomass	Average wet season crude protein
Average dry season crude protein	Average wet season dry matter digestibility
Average dry season DMD	Average ratio dry matter digestibility to crude protein during wet season
Average ratio DMD:CP during dry season	Average ratio faecal phosphorus to metabolisable energy during wet season
Provision of supplemental nitrogen	
Provision of supplemental phosphorus	
Animal	
Cow-age class	Body condition score at the branding or weaning muster
Estimated period of calving expressed as predicted window when the cow calved	Body condition score change between pregnancy diagnosis and branding or weaning muster
Liveweight at the pregnancy diagnosis muster	
Body condition score at the pregnancy diagnosis muster	

8.4.3 Multivariable model results

An explanatory multivariable model was developed to identify the major drivers for the occurrence of non-pregnancy based on the results from the unconditional analysis (Table 8-2). The resulting dataset represented 73% (55) and 55% (32,382) of herds and animal production cycles, respectively that were included in the starting dataset. The remainder of the records had a missing value for at least one of the risk factors contained in the final model. On average, each herd and individual cow contributed information relating to 589 (range 54-5210) and 1.3 (range 1-3) animal production years, respectively in the final model. In the final model, the proportion of the total variance within our data that was explained by the variance between herd was 18.4%. The final multivariable model explained 28.1% of the variance at the property level that had been estimated using an intercept only model.

Table 8-2. The final multivariable logistic regression model summarising herd-adjusted associations between risk factors and the odds of non-pregnancy in commercial beef cows of northern Australia, with adjusted OR, 95% confidence intervals and P value. Data drawn from 32,382 annual production years involving 24,736 individual cows from 55 herds.

Variable	Coefficient	SE	Adjusted OR	95% CI of OR Lower	Upper	*P* value[a]
Country type						**<0.001**
Northern Downs	Ref					
Southern Forest	-1.63	0.53	0.52	0.23	1.17	0.12
Central Forest	-0.65	0.41	2.48	1.23	5.01	0.01
Northern Forest	0.91	0.36	0.20	0.07	0.56	<0.01
Year observed						**<0.001**
2009	Ref					
2010	0.25	0.12	1.28	1.02	1.62	0.03
2011	0.54	0.13	1.72	1.33	2.21	<0.01
Cow-age class						**<0.001**
First-lactation cows	0.99	0.11	2.68	2.16	3.33	<0.01
Mature cows	Ref					
Aged cows	-0.08	0.11	0.92	0.74	1.15	0.47
Reproductive outcome of the previous production cycle						**<0.001**
Jul to Sep	-0.37	0.14	0.69	0.53	0.90	<0.01
Oct to Nov	Ref					
Dec to Jan	0.28	0.09	1.33	1.11	1.59	<0.01
Feb to Mar	1.27	0.11	3.55	2.85	4.43	<0.01
Apr to Jun	2.17	0.14	8.74	6.62	11.54	<0.01
Pregnant	1.49	0.12	4.45	3.49	5.67	<0.01
Non-pregnant	-1.16	0.16	0.31	0.23	0.43	<0.01
FTR	-0.08	0.22	0.93	0.60	1.42	0.73
Average DMD during the dry season†						**<0.001**
<55	Ref					
≥55	-0.80	0.14	0.45	0.35	0.59	<0.01
Average FP:ME during wet season‡						**0.01**
<500 mgP:1 MJME	Ref					
≥500 mgP:1 MJME	0.54	0.21	1.71	1.13	2.60	0.01
Average DMD:CP during wet season‡						**0.25**
>8:1	Ref					
≤8:1	-0.16	0.14	0.85	0.65	1.12	0.25
BCS at branding/weaning muster†						**<0.001**
1 to 2	1.42	0.10	4.13	3.38	5.04	<0.01
2.5	0.84	0.09	2.33	1.95	2.77	<0.01
3	Ref					
3.5	-0.31	0.12	0.73	0.58	0.93	0.01
4 to 5	-0.03	0.15	0.97	0.73	1.29	0.82
Interaction: Average FP:ME during wet season‡ x Average DMD:CP during wet season‡						**<0.001**
≥500 mgP:1 MJME: ≤8:1	-1.46	0.16	0.23	0.17	0.32	<0.01
Interaction: Country type x Average FP:ME during wet season†						**<0.001**
Southern Forest: ≥500 mgP:1 MJME	0.56	0.20	1.75	1.17	2.61	<0.01
Central Forest: ≥500 mgP:1 MJME	0.26	0.17	1.30	0.94	1.81	0.12
Northern Forest: ≥500 mgP:1 MJME	-0.59	0.21	0.55	0.37	0.83	<0.01

Table 8-2. Continued.

Variable	Coefficient	SE	Adjusted OR	95% CI of OR Lower	Upper	*P* value[a]
Interaction: Reproductive outcome of the previous production cycle x Cow-age class						**<0.001**
First-lactation cows: Jul to Sep	0.09	0.14	1.10	0.83	1.45	0.51
First-lactation cows: Dec to Jan	0.03	0.11	1.03	0.83	1.27	0.81
First-lactation cows: Feb to Mar	-0.06	0.16	0.94	0.69	1.28	0.70
First-lactation cows: Apr to Jun	-1.46	0.35	0.23	0.12	0.47	<0.01
First-lactation cows: Pregnant	-0.13	0.24	0.88	0.55	1.42	0.60
First-lactation cows: Non-pregnant	-0.77	0.20	0.46	0.31	0.68	<0.01
First-lactation cows: FTR	-0.37	0.21	0.69	0.46	1.03	0.07
Aged cows: Jul to Sep	0.39	0.19	1.48	1.02	2.15	0.04
Aged cows: Dec to Jan	-0.09	0.11	0.91	0.73	1.14	0.42
Aged cows: Feb to Mar	0.10	0.14	1.10	0.84	1.45	0.48
Aged cows: Apr to Jun	0.04	0.20	1.04	0.71	1.54	0.83
Aged cows: Pregnant	0.46	0.15	1.58	1.18	2.12	<0.01
Aged cows: Non-pregnant	0.81	0.18	2.24	1.59	3.17	<0.01
Aged cows: FTR	0.45	0.22	1.57	1.02	2.40	0.04
Interaction: Country type x Average DMD:CP during wet season‡						**<0.001**
Central Forest: ≤8:1	1.85	0.40	5.40	3.41	8.54	<0.01
Northern Forest: ≤8:1	1.69	0.23	0.90	0.64	1.28	0.56
Southern Forest: ≤8:1	-0.10	0.18	6.37	2.92	13.90	<0.01
Interaction: Reproductive outcome of the previous production cycle x BCS at branding/weaning muster†						**<0.001**
Jul to Sep: 1 to 2	-0.55	0.18	0.58	0.40	0.83	<0.01
Jul to Sep: 2.5	-0.27	0.15	0.76	0.56	1.03	0.08
Jul to Sep: 3.5	0.09	0.21	1.09	0.72	1.65	0.67
Jul to Sep: 4 to 5	0.02	0.30	1.02	0.57	1.83	0.94
Dec to Jan: 1 to 2	0.16	0.12	1.17	0.92	1.49	0.19
Dec to Jan: 2.5	0.11	0.11	1.12	0.90	1.40	0.31
Dec to Jan: 3.5	0.27	0.15	1.30	0.98	1.74	0.07
Dec to Jan: 4 to 5	0.15	0.17	1.16	0.82	1.63	0.40
Feb to Mar: 1 to 2	0.04	0.17	1.04	0.75	1.44	0.82
Feb to Mar: 2.5	-0.08	0.15	0.92	0.68	1.23	0.57
Feb to Mar: 3.5	0.26	0.18	1.30	0.92	1.84	0.13
Feb to Mar: 4 to 5	-0.05	0.25	0.95	0.58	1.56	0.84
Apr to Jun: 1 to 2	-0.90	0.33	0.41	0.21	0.78	<0.01
Apr to Jun: 2.5	0.44	0.28	1.56	0.90	2.70	0.11
Apr to Jun: 3.5	0.55	0.22	1.74	1.13	2.68	0.01
Apr to Jun: 4 to 5	1.22	0.37	3.39	1.65	6.97	<0.01
Pregnant: 1 to 2	-1.51	0.19	0.22	0.15	0.32	<0.01
Pregnant: 2.5	-0.44	0.17	0.64	0.46	0.89	<0.01
Pregnant: 3.5	1.03	0.19	2.80	1.94	4.06	<0.01
Pregnant: 4 to 5	1.23	0.21	3.41	2.27	5.12	<0.01
Non-pregnant: 1 to 2	-0.71	0.44	0.49	0.21	1.16	0.11
Non-pregnant: 2.5	-0.12	0.30	0.88	0.49	1.60	0.69
Non-pregnant: 3.5	-0.09	0.20	0.91	0.61	1.35	0.64
Non-pregnant: 4 to 5	0.53	0.21	1.70	1.13	2.55	0.01
FTR: 1 to 2	0.15	0.40	1.16	0.53	2.55	0.71
FTR: 2.5	-0.55	0.37	0.58	0.28	1.19	0.14
FTR: 3.5	-0.01	0.26	0.99	0.59	1.66	0.98
FTR: 4 to 5	0.20	0.26	1.22	0.74	2.01	0.45

Table 8-2. Continued.

Variable	**Coefficient**	**SE**	**Adjusted OR**	**95% CI of OR** Lower	Upper	***P* value**[a]
Interaction: BCS at branding/weaning muster† x Cow-age class						<0.001
First-lactation cows: 1 to 2	-0.55	0.13	0.58	0.45	0.74	<0.01
First-lactation cows: 2.5	-0.16	0.11	0.85	0.68	1.06	0.15
First-lactation cows: 3.5	-0.43	0.14	0.65	0.49	0.85	<0.01
First-lactation cows: 4 to 5	-0.65	0.16	0.52	0.38	0.71	<0.01
Aged cows: 1 to 2	0.12	0.12	1.12	0.89	1.43	0.34
Aged cows: 2.5	-0.08	0.11	0.92	0.74	1.15	0.47
Aged cows: 3.5	0.15	0.12	1.16	0.91	1.47	0.22
Aged cows: 4 to 5	-0.15	0.15	0.86	0.65	1.15	0.31
Intercept	-2.57	0.33				
Random effect				**95% CI Lower**	**95% CI Lower**	
Level 2 (property)			0.862	0.7	1.06	
rho (ICC)			0.184	0.13	0.25	

Abbreviations: BCS, body condition score; FP:ME, ratio of faecal phosphorus to metabolisable energy; DMD:CP, Ratio of dry matter digestibility to dietary crude protein; FTR, confirmed pregnant in the previous production cycle and subsequently not recorded to lactate in the following year.
*Bold values are generalised Wald-test P values; others are Wald-test values.
†conducted approximately 3-4 months prior to the pregnancy diagnosis muster which the non-pregnancy outcome was determined.

The final model had an acceptable ability to discriminate between those cows that were positive for non-pregnancy and those that were not, with 69.9% correct predictions while the area under the receiver operating curve was 0.76 (95% CI, 0.76-0.77). Sensitivity was high (>0.90) at low probability cut points (<0.1) while, specificity was high (>0.90) at probability cut points >0.5. The fixed part of final multivariable model fitted the data only partially well with fewer cases of non-pregnancy than expected at lower probabilities. The *P* value for the Hosmer-Lemeshow goodness-of-fit statistic was <0.001, indicating a poor fit. Potential outlier and influential data points were evaluated and an inspection of the covariate values revealed that all values were plausible, and as a result all observations were retained in the analysis (The performance of the final model is further described in Section 8.8.2).

The mean probability of non-pregnancy, expressed as a percentage, was estimated using the final model for each level of risk factors not dependent on the effects of other risk factors, and for each interaction between risk factors to improve the practical interpretation of results (Table 8-3).

Table 8-3. Model predicted means for percentage of cows non-pregnant for risk factors and interactions between risk factors. Predicted mean percentages are based on estimated marginal means generated from the final multivariable model and are adjusted for all other explanatory variables contained in the model.

Variable	N	Mean (%)	95% CI of Mean	
			Lower	Upper
Year observed				
2009	2138	11.9	8.4	15.5
2010	19546	14.8	11.3	18.3
2011	10698	18.8	14.5	23.2
DMD during the dry season*				
<55	28054	20.8	16.2	25.4
≥55	4328	10.6	7.5	13.7
Interaction: Average FP:ME during wet season† x average DMD:CP during wet season†				
<500 mgP:1 MJME: >8:1	8772	11.7	8.1	15.4
≥500 mgP:1 MJME: >8:1	1295	19.4	13.9	24.9
<500 mgP:1 MJME: ≤8:1	12494	10.1	7.5	12.7
≥500 mgP:1 MJME: ≤8:1	9821	21.1	16.3	25.8
Interaction: Country type x average FP:ME during wet season†				
Southern Forest: <500 mgP:1 MJME	2431	7.9	3.2	12.6
Southern Forest: ≥500 mgP:1 MJME	3928	11.0	5.0	17.0
Central Forest: <500 mgP:1 MJME	7963	17.3	9.7	24.8
Central Forest: ≥500 mgP:1 MJME	3066	18.4	10.6	26.1
Northern Downs: <500 mgP:1 MJME	1849	14.7	7.9	21.5
Northern Downs: ≥500 mgP:1 MJME	2473	12.5	6.1	18.9
Northern Forest: <500 mgP:1 MJME	9023	28.9	20.3	37.5
Northern Forest: ≥500 mgP:1 MJME	1649	15.7	9.3	22.1
Interaction: Reproductive outcome of the previous production cycle x Cow-age class				
First-lactation cows: Jul to Sep	1472	14.8	11.1	18.4
First-lactation cows: Oct to Nov	1997	10.2	7.3	13.1
First-lactation cows: Dec to Jan	1350	21.3	16.3	26.3
First-lactation cows: Feb to Mar	407	37.4	28.8	46.1
First-lactation cows: Apr to Jun	48	31.5	16.4	46.6
First-lactation cows: Pregnant	109	41.9	29.7	54.1
First-lactation cows: Non-pregnant	776	2.3	1.3	3.2
First-lactation cows: FTR	588	9.6	6.1	13.2
Mature cows: Jul to Sep	1581	8.5	6.3	10.7
Mature cows: Oct to Nov	5097	5.2	3.6	6.9
Mature cows: Dec to Jan	5694	12.4	9.3	15.4
Mature cows: Feb to Mar	1650	25.4	19.6	31.2
Mature cows: Apr to Jun	548	51.3	42.1	60.5

Abbreviations: BCS, body condition score; FP:ME, ratio of faecal phosphorus to metabolisable energy; DMD:CP, Ratio of dry matter digestibility to dietary crude protein; FTR, confirmed pregnant in the previous production cycle and subsequently not recorded to lactate in the following year.
*relates to the 3-4 months leading up to the determination of non-pregnancy outcome.
†relates to the wet season after the pregnancy diagnosis muster of previous production cycle and when majority of cows were likely to have last calved.

Table 8-3. Continued.

Variable	N	Mean (%)	95% CI of Mean	
			Lower	Upper
Mature cows: Pregnant	1288	30.5	24.1	36.8
Mature cows: Non-pregnant	2463	2.6	1.7	3.5
Mature cows: FTR	814	7.6	4.9	10.3
Aged cows: Jul to Sep	520	7.9	5.6	10.2
Aged cows: Oct to Nov	1442	7.1	4.4	9.8
Aged cows: Dec to Jan	2214	10.7	7.8	13.6
Aged cows: Feb to Mar	709	25.9	19.5	32.3
Aged cows: Apr to Jun	230	50.6	39.7	61.5
Aged cows: Pregnant	449	39.1	31.0	47.3
Aged cows: Non-pregnant	658	5.3	3.3	7.3
Aged cows: FTR	278	10.7	6.4	15.1
Interaction: BCS at branding/weaning muster* x Cow-age class				
First-lactation cows: 1 to 2	1052	23.1	16.7	29.4
First-lactation cows: 2.5	1357	25.1	18.9	31.3
First-lactation cows: 3	1762	16.0	11.7	20.2
First-lactation cows: 3.5	1485	10.5	7.4	13.6
First-lactation cows: 4 to 5	1091	12.6	8.6	16.5
Mature cows: 1 to 2	1877	21.3	15.8	26.7
Mature cows: 2.5	3162	17.1	12.7	21.4
Mature cows: 3	6571	9.0	6.6	11.4
Mature cows: 3.5	4342	8.6	6.3	10.9
Mature cows: 4 to 5	3183	12.6	9.2	16.0
Aged cows: 1 to 2	835	26.9	19.9	33.8
Aged cows: 2.5	1089	18.7	13.6	23.7
Aged cows: 3	2310	10.7	7.7	13.7
Aged cows: 3.5	1408	11.7	8.4	15.0
Aged cows: 4 to 5	858	13.1	9.1	17.1
Interaction: Country type x average DMD:CP during wet season†				
Southern Forest: >8:1	142	6.0	1.4	10.6
Southern Forest: ≤8:1	4180	14.3	7.9	20.6
Central Forest: >8:1	621	12.7	6.2	19.2
Central Forest: ≤8:1	5738	24.4	15.2	33.6
Northern Downs: >8:1	3415	19.7	10.4	29.0
Northern Downs: ≤8:1	7614	9.1	4.6	13.7
Northern Forest: >8:1	5889	31.1	21.7	40.5
Northern Forest: ≤8:1	4783	14.3	9.0	19.7
Interaction: Reproductive outcome of the previous production cycle x BCS at branding/weaning muster*				
Jul to Sep: 1 to 2	477	12.5	8.4	16.6
Jul to Sep: 2.5	875	10.1	7.1	13.2
Jul to Sep: 3	1271	6.5	4.4	8.5

Abbreviations: BCS, body condition score; FP:ME, ratio of faecal phosphorus to metabolisable energy; DMD:CP, Ratio of dry matter digestibility to dietary crude protein; FTR, confirmed pregnant in the previous production cycle and subsequently not recorded to lactate in the following year.
*relates to the 3-4 months leading up to the determination of non-pregnancy outcome.

†relates to the wet season after the pregnancy diagnosis muster of previous production cycle and when majority of cows were likely to have last calved.

Table 8-3. Continued.

Variable	N	Mean (%)	95% CI of Mean	
			Lower	Upper
Jul to Sep: 3.5	687	4.8	2.9	6.7
Jul to Sep: 4 to 5	263	5.0	2.4	7.6
Oct to Nov: 1 to 2	1145	23.4	18.0	28.7
Oct to Nov: 2.5	1661	15.5	11.7	19.3
Oct to Nov: 3	3139	7.9	5.8	10.0
Oct to Nov: 3.5	1621	5.4	3.7	7.0
Oct to Nov: 4 to 5	970	5.9	3.9	8.0
Dec to Jan: 1 to 2	1266	31.7	25.2	38.2
Dec to Jan: 2.5	1451	21.1	16.2	25.9
Dec to Jan: 3	3576	10.0	7.3	12.7
Dec to Jan: 3.5	1919	8.8	6.3	11.3
Dec to Jan: 4 to 5	1046	8.7	5.9	11.4
Feb to Mar: 1 to 2	495	53.3	44.4	62.2
Feb to Mar: 2.5	510	37.7	29.8	45.7
Feb to Mar: 3	1055	23.5	17.7	29.3
Feb to Mar: 3.5	537	21.0	15.1	27.0
Feb to Mar: 4 to 5	169	17.8	10.7	24.8
Apr to Jun: 1 to 2	58	40.5	24.1	56.9
Apr to Jun: 2.5	218	60.9	47.5	74.4
Apr to Jun: 3	308	31.8	23.0	40.6
Apr to Jun: 3.5	181	35.0	24.5	45.5
Apr to Jun: 4 to 5	61	53.9	36.3	71.5
Pregnant: 1 to 2	242	25.2	17.4	32.9
Pregnant: 2.5	374	36.9	28.2	45.5
Pregnant: 3	508	29.8	22.1	37.4
Pregnant: 3.5	360	44.1	34.8	53.4
Pregnant: 4 to 5	362	51.7	42.3	61.0
Non-pregnant: 1 to 2	44	4.5	0.8	8.2
Non-pregnant: 2.5	183	4.9	2.1	7.6
Non-pregnant: 3	828	2.6	1.7	3.6
Non-pregnant: 3.5	1442	1.6	1.0	2.2
Non-pregnant: 4 to 5	1400	3.3	2.2	4.4
FTR: 1 to 2	37	25.3	11.4	39.1
FTR: 2.5	85	9.2	3.7	14.7
FTR: 3	209	7.5	4.3	10.7
FTR: 3.5	488	5.1	3.2	7.0
FTR: 4 to 5	861	6.8	4.6	9.0

Abbreviation: FTR, confirmed pregnant in the previous production cycle and subsequently not recorded to lactate in the following year.

The occurrence of non-pregnancy was associated with the reproductive outcome of the previous production cycle (including time of calving) (P<0.001). However, this association was dependent on both BCS measured at the branding/weaning muster ($P<0.001$) and cow-age class ($P<0.001$; Table 8-2). For those cows that lactated in the current production cycle, the occurrence of non-pregnancy generally increased as category of reproductive outcome (calving period) increased with the expected occurrence of non-pregnancy ranging between 8-15% for cows age cohorts that calved between July to September, compared to 25-37% for those that calved between February to March (Table 8-3). Generally, the occurrence of non-pregnancy decreased with increasing body condition score for those cows that contributed a weaner, while there was little separation in the expected occurrence of non-pregnancy at different BCS categories for cows that did not lactate in the current year. The differentiation between BCS categories ≤3 measured at the branding/weaning muster was greater for cows that calved later in the calving window than those that calved earlier. The estimated reduction in non-pregnancy between BCS≤2 compared to BCS=3 measured at the branding/weaning muster for heifers and cows predicted to previously calve between July and September (likely to have been lactating for 7-8 months at time of BCS assessment) was 6.0% (95% CI, 2.7-9.3%; $P<0.01$) compared to 29.8% (95% CI, 23.1-36.4%; $P<0.01$) for heifers and cows predicted to previously calve between February and March (likely to have been lactating for 2-4 months at time of BCS assessment).

The associated effect of BCS measured at the branding/weaning muster (approximately 3-4 months prior to pregnancy diagnosis) was also dependent on cow age cohort ($P<0.001$; Table 8-2). Generally, the expected occurrence of non-pregnancy progressively decreased with diminishing reductions in occurrence of non-pregnancy between BCS categories as BCS measured at the branding/weaning muster increased. The expected occurrence of non-pregnancy was estimated to reduce by 7.1 (95% CI, 2.6-11.6; $P<0.01$), 12.3 (95% CI, 8.4-16.1; $P<0.01$) and 16.2 (95% CI, 10.9-21.4; $P<0.01$) percentage points in first-lactation, mature and aged cows, respectively when BCS measured at the branding/weaning muster increased from ≤2 to 3. Minimal differences in the expected occurrence of non-pregnancy were predicted across cow-age cohorts at higher BCS categories although, there was a small but significant increase in the expected occurrence of non-pregnancy for cows in the highest category of BCS.

With the exception of both cows which were not pregnant in the previous production cycle or were pregnant and subsequently were not recorded to lactate the following year, the expected occurrence of non-pregnancy was highest in first-lactation cows, and mature cows not dissimilar to aged cows. In cows that had calved between July and March, the expected occurrence of non-pregnancy ranged between 5-12 percentage points higher in first-lactation cows, compared to mature and aged cows ($P<0.05$). In contrast, the expected occurrence of non-pregnancy was ~20 percentage points lower for first-lactation cows estimated to calve between April and May relative to mature and aged cows (P<0.05). The expected occurrence of non-pregnancy was <10% for cows that did not lactate in the current year. Compared to cows non-pregnant in the previous production cycle, the expected occurrence of non-pregnancy for cows confirmed pregnant in the previous production cycle and subsequently not recorded to lactate in the current cycle (FTR) was 5-8 percentage points higher (P<0.01).

After adjustment for all other factors contained in the full multivariable model, the occurrence of non-pregnancy was associated with production year with the expected occurrence of non-pregnancy increasing across years and each production year determined to be statistically significant from each other (P<0.05).

Indices summarising the nutritional conditions (protein and phosphorus) during the wet season when the majority of cows were expected to have last calved was found to be associated with the occurrence of non-pregnancy and were dependant on country type and each other. When dietary protein content of the wet season pasture was low (DMD:CP >8:1) percent non-pregnancy was predicted to increase by 10.6 (95%CI 4.5-16.6; P<0.01) and 16.8 (95%CI, 11.7-21.9; P<0.01) percentage points in the Northern Forest and Downs, respectively when compared to heifers and cows grazing wet pastures with DMD:CP <8:1. However, in Southern and Central Forest country types, percent non-pregnancy reduced by 8.3 (95%CI, 3.2-13.4; P<0.01) and 11.7 (95%CI, 5.3-18.0; P<0.01) percentage points, respectively.

The risk of phosphorus deficiency was only associated with occurrence of non-pregnancy in the country type Northern Forest (P<0.01) and not in Southern and Central Forest, and Northern Downs (P>0.05, P=0.59 and P=0.22, respectively). In the Northern Forest, where the risk of phosphorus deficiency was low (≥500 FP:ME ratio) the expected occurrence of non-pregnancy was 13.2 percentage points (95% CI, 8.0-18.5, P<0.01) lower when compared to where risk was high (<500 FP:ME ratio).

For cows that grazed pastures of adequate protein during the wet season, the expected occurrence of non-pregnancy was 10.9 percentage points (95% CI, 8.2-13.7, P<0.01) higher where risk of phosphorus deficiency was low, compared to where risk of phosphorus deficiency was high. A similar response was observed for cows that grazed pastures of adequate protein during the wet season, the expected occurrence of non-pregnancy was 7.7 percentage points (95% CI, 3.2-12.2, *P*<0.01) higher where risk of phosphorus deficiency was low, compared to where risk of phosphorus deficiency was high.

In cows that grazed pastures <55% DMD during the dry season, which related to the 3-4 months prior to the determination of the outcome non-pregnancy, the expected occurrence of non-pregnancy was 10.2 percentage points (95% CI, 6.6-13.8, *P*<0.01) higher than for cows that grazed pastures ≥55% dry matter digestibility.

8.4.4 Population attributable fraction

The estimated population attributable fractions (PAF) of non-pregnancy for risk factors retained in the full multivariable model are presented in Table 8-4. Estimates of the proportional reduction in the expected occurrence of non-pregnancy for the study population should be interpreted with some caution as all interaction terms contained in the final model were omitted from the model the estimates of PAF are based on. Based on PAF estimates, top-order determinants for occurrence of non-pregnancy were period of calving and average DMD of dry season pasture. Also, body condition score at the branding/weaning muster and wet season nutritional risk factors were thought to be of similar importance, as were year observed, cow-age cohort and country-type.

Table 8-4. Estimated population attributable fraction of non-pregnancy for risk factors contained in the full multivariable model.

Variable	PAF	95% Confidence Intervals	
		Lower	Upper
Previous reproductive outcome	76.1%	73.2%	78.6%
Average DMD during the dry season	62.1%	54.8%	68.2%
BCS at the weaning/branding muster	38.3%	34.1%	42.3%
Average FP:ME ratio during the wet season	34.2%	29.4%	38.6%
Average DMD:CP ratio during the wet season	13.0%	9.4%	16.4%
Year observed	6.4%	4.2%	8.5%
Cow-age cohort	6.0%	0.1%	11.6%
Country type	3.5%	-63.0%	42.9%

8.5 Discussion

This study is thought to be the first population-based epidemiologic study to determine the factors associated with pregnancy in commercial beef herds of Australia and its findings further demonstrated the effects of time of calving, lactation and pre- and post-partum nutrition. This study also provided an opportunity of estimate the average percent non-pregnancy in beef herds in northern Australia. The mean percentage non-pregnancy in beef herds was estimated as 23.9%. When restricted to each of four country types, the average percent non-pregnancy in beef herds was

32.1%, 17.1%, 16.0% and 13.2% for the Northern Forest, Northern Downs, Central Forest and Southern Forest, respectively. This finding highlights the sizeable difference in reproductive performance of cows in the Northern Forest compared to other country types which is likely to represent the extreme environmental and nutritional challenges faced by beef producers within this country type. Using these estimates of pregnancy and an overall estimate of 9.5% foetal/calf loss McGowan *et al.* (2014), a potential estimate of weaning rate across northern Australia is therefore, 69% and 61%, 75%, 76%, and 79% for Northern Forest, Northern Downs, Central Forest and Southern Forest, respectively. These high levels of non-pregnancy observed in the Northern Forest suggest that maintaining a self-replacing herd would not be possible if cows were routinely culled for non-pregnancy each year.

Population attributable fraction estimates are useful for providing a measure of the relative importance of risk factors, as both the strength of the risk factors' association with the non-pregnancy and the prevalence of the risk factor within the population is computationally included in its estimation. It is acknowledged that a shortcoming of the PAF estimates reported here is that interaction terms contained in the final model were omitted from the model used to estimate PAF for each risk factor due to computational limitations. Therefore, presented PAF results should be interpreted with appropriate caution and emphasis is suggested to be placed towards the likely relative importance of different risk factors rather than the PAF estimate.

These analyses reaffirm that the reproductive outcome of the previous production cycle (including time of calving) is a top order determinant for occurrence of non-pregnancy which is consistent with O'Rourke *et al.* (1991b) findings that cows calving earlier in the year had fewer occurrences of non-pregnancy. Cows that calve earlier in the calving period have greater time to return to normal ovarian activity by the end of the mating period increasing their probability of pregnancy. Furthermore, the additional nutritional requirements of lactation for cows that calve early in the calving period are more likely correspond to first rains of the season (Nicholls *et al.* 1982) and improving pasture quality and quantity. Due to not experiencing the increased nutritional drain of lactation in the current production cycle, the occurrence of non-pregnancy was lowest (<5%) in cows determined to be 'not pregnant' in the previous production cycle (Mackinnon *et al.* 1989). However, for cows diagnosed as pregnant in the previous production cycle and subsequently did not lactate in the current production cycle, a 4-5 percentage point higher expected occurrence of non-pregnancy was predicted, potentially suggesting that cows were likely to have carried the pregnancy near or to full term and then lost a calf, incurring some adverse effects of pregnancy and potentially lactation.

The occurrence of non-pregnancy for different cow-age classes was dependent on their reproductive outcome in the previous production cycle. With the exception of cows predicted to have calved between April and May and cows that did not lactate in the current production cycle, the expected occurrence of non-pregnancy was 5-12 percentage points higher in first-lactation cows, compared to mature and aged cows ($P<0.05$), which is supported by Entwistle (1983) and Burns *et al.* (2010). However, was ~20 percentage points lower for cows that had calved between April and May. This finding is not completely understood, however, it is potentially explained by calves of first-lactation cows weaned at earlier ages than other cow-age class cohorts with potential radical weaning of calves from this calving period, reducing period of lactation the associated nutritional drain. Minimal differences in the expected occurrence of non-pregnancy were estimated between cow-age cohorts that did not lactate in the current production cycle.

The large and consistent effect of nutritional risk factors on the occurrence of non-pregnancy was demonstrated by the large number contained in the final model, which were: country type, BCS measured at the branding/weaning muster; inadequate wet season pasture protein; risk of phosphorus deficiency and low digestibility of dry season pasture. As BCS measured at the branding/weaning muster increased, the expected occurrence of non-pregnancy progressively declined with diminishing reductions predicted between BCS categories. These findings are consistent with numerous other studies where curvilinear or linear relationships between improvement in body condition and positive responses in fertility have been demonstrated (Rae *et al.* 1993; Jolly *et al.* 1996; Dixon 1998; Wettemann *et al.* 2003; Schatz and Hearnden 2008). In the present study, relative to the odds of non-pregnancy at BCS 3 measured at the branding/weaning muster, the odds of non-pregnancy were 2.3 times greater at BCS 2.5 and 4.1 times greater at BCS ≤2.0 and are very similar to those reported by Waldner and García Guerra (2013) who using a multivariable model that included other risk factors including cow age, cow breed type, exposure to a single bull, duration of bull exposure during the breeding season, and month of pregnancy testing reported odds ratios of 1.3-1.8 at BCS 2.5 and 3.5-4.2 at BCS 2.0 when referenced to BCS 3.0 measured at the pregnancy diagnosis muster. With respect to the interaction between BCS and cow-age class, the lowest expected occurrence of non-pregnancy was in mature cows BCS measured at the branding/weaning muster between 3 and 3.5. Mature cows performed better on most occasions than both aged cows (1.0-2.4 percentage points) and first-lactation cows (1.8-8.0 percentage points), except for those cows in the highest BCS where there was no effect of cow-age class. The biological mechanism explaining the increased expected occurrence of non-pregnancy for first-lactation cows is thought to be explained by the increased nutritional demands of having to support both lactation and maternal growth (Entwistle 1983). These findings further validate current recommendations that to maximise pregnancies herd managers should aim to wean calves when all cow-age classes at BCS 3 or greater.

The importance of good nutrition during both wet and dry seasons in order to achieve sound levels of reproductive performance was emphasised by the findings of the current study with low wet season pasture protein, low available energy during the dry season (between weaning and pregnancy diagnosis) and risk of phosphorus deficiency increasing the occurrence of non-pregnancy. With the exception of the risk factor describing the available metabolisable energy during the dry season, the magnitude of effect for each of these risk factors was dependent on country type. The 10.6 and 16.8 percentage point increase in the expected occurrence of non-pregnancy for cows grazing wet season pastures low in protein relative to the available energy (DMD:CP >8:1 ratio) within the Northern Downs and Northern Forest, respectively when compared to cows grazing pastures DMD:CP <8:1, is consistent with demonstrated improvements in pregnancy percentages from the provision of supplemental protein during the wet season reported by McCosker *et al.* (1991). There are obvious logistical constraints to remedial management strategies to target this effect within Northern Downs and Forest such as the toxic nature of common non-protein nitrogen sources when wet. It is unclear why the direction of effect for this risk factor changed within Southern and Central Forest country types however, it is potentially partially explained by differences in distribution and timing of calving and lactation. The increased supply of protein during early lactation favours partitioning of available nutrients to mammary secretion (Oldham 1984), thus increasing the risk of negative energy balance which can impact the ability of cows to cycle in early- or during lactation (Roche *et al.* 2013).

Where the risk of phosphorus deficiency was high, compared to where the risk of phosphorus deficiency was low, a 13.2 percentage point higher expected occurrence of non-pregnancy was estimated in the Northern Forest and is consistent with findings reported by McCosker *et al.* (1991) and Hart and Michell (1965). It is unclear why similar responses were not observed for other regions however this effect is potentially explained by differences in soil phosphorus status of different land systems (Jackson 2012). The association between wet season pasture protein content and risk of phosphorus deficiency is also largely consistent with current knowledge that there is limited benefit to the provision of dietary P when the available protein supply is limited (Jackson 2012). Although, the observed higher percent non-pregnancy in cows grazing wet season pastures of low protein where risk of phosphorus deficiency was low, compared to high risk of phosphorus deficiency is unclear. However, it is potentially representing the very low performance observed for some properties within regions typically considered to be of adequate phosphorus status that were in drought during approximately 12-18 months during the study period.

The association between available metabolisable energy derived from pasture during the dry season and occurrence of non-pregnancy was consistent across country types with 10.2 percentage point increase in expected occurrence of non-pregnancy in cows that grazed pastures <55% DMD, compared to those that grazed pastures ≥55% DMD. Generally, weaning approximately coincides with the commencement of the dry season and therefore, this finding is likely to relate to either cows which either calved later in the calving period or those cows that calved earlier in the calving period although have failed to conceive while lactating under continuously mated bull management systems. The biological mechanism for this association is potentially explained by cows grazing pastures of lower digestibility being at greater risk of negative energy balance and down regulation of folliculogenesis resulting in increased probability of anovulation (Scaramuzzi *et al.* 2011).

In the present study, the expected occurrence of non-pregnancy varied by 2.9-6.9 percentage points between production years and is considered to represent seasonal differences not elsewhere accounted for by other risk factors and is consistent with previous studies (O'Rourke 1994). This finding further highlights the importance of conducting research studies over a number of years. Variability between years is typical for a wet-dry tropical system and others have previously recommended that ecological studies conducted within the northern regions of northern Australia should continue for 6-8 years (Taylor and Tulloch 1985). In the present study, typical of this seasonal variability there were periods of extended dry and large rainfall events causing widespread flooding within some regions. It should be noted, that production year was not found to modify the impact of other risk factors and demonstrates the consistency of its associated effect.

The population attributable fraction of non-pregnancy in cows for each risk factor determined as being major predictors of non-pregnancy were estimated to enable a comparison of their relative importance and provide a method by which those risk factors identified to be important predictors could be ranked. The analyses reaffirmed that reproductive history and average dry season DMD are top-order determinants of the occurrence of non-pregnancy. The estimated proportional reduction in expected occurrence of non-pregnancy for BCS measured at the branding/weaning muster and risk of phosphorus deficiency indicated that they were of similar importance, as was country type, cow-age class and production year.

It is acknowledge that the study population of properties and herds were identified using a non-random process aimed at enrolling representative herds where good cooperation was highly-likely to be achieved may not be seamlessly representative of the target population. The herd managers that participated in the study could be considered the more progressive managers of northern Australia. Therefore, appropriate caution should be exercised when interpreting results as they may reflect those of a population operating slightly above typical and despite appropriate diligence being placed on recording of data there were some practical limitations of capturing observational data under commercial conditions.

While there are several modelling options to analyse binary data with hierarchical structure, the method with which models computationally handle clustering or grouping of data can be generally categorised as either having a “population-averaged” or “subject-specific” approach.

Random-effect logistic regression models were employed in the present study, generating subject-specific estimates of regression coefficients (odds ratios), and predicted probabilities. Subject-specific models explicitly manage dependencies by incorporating a random effect for each subject in the model (random intercept). Because the estimated effects are adjusted for unmeasured individual differences, they are termed “subject-specific” effects. Odds-ratios estimated from the subject-specific model should be interpreted as representing the change for a single individual or for those individuals with the same random effect estimate.

The population-averaged model describes changes in the population mean given changes in covariates, and does not have a subject-specific focus. Odds-ratios estimated from the population-averaged model should be interpreted as representing the change for an average subject. Population-averaged effect estimates, although not reported, were generated and were found to be numerically very similar to those generated using subject-specific estimators. For the more informed reader equations exist to convert subject-specific effect estimates to population averaged such as those reported by Dohoo *et al.* (2009).

Adding the fixed effects to the model explained 28% of the variance at the property level that had been estimated in the intercept only model suggests that important factors were included in the final model that contributed to the odds of non-pregnancy. However, the residual intra-class correlation estimate (0.18) in the selected model indicates that there is still a relatively large amount of variance in non-pregnancy that is at the property level and improvements to the modelling could result from further refinement of the variables considered in the final model or addition of further variables.

8.6 Conclusions

The findings of this study reaffirm a number of risk factors can have large and moderating effects on occurrence of non-pregnancy. In beef herds of northern Australia, management strategies that support the majority of cows to readily conceive early in the mating period with sustainable pasture management practices supported by appropriate nutritional management is critical to ensure adequate levels of reproductive performance.

8.7 Contributions by others to the chapter

Mr McCosker was responsible for the management of the data across all country types and capturing the data within the country type of Northern Forrest. Mr McCosker conducted preliminary univariate and multivariate analyses and supported Professor Perkins, who completed the final multivariate analyses. Further model checking of the selected model and estimation of the population attributable fractions were completed by Mr McCosker. Mr McCosker contributed significantly to the interpretation of the data and was responsible for the writing of the chapter. Data cleaning was overseen by Professor O'Rourke. Professor McGowan led the development of the design in conjunction with Dr Fordyce, Professor O'Rourke and Professor Perkins. Professor McGowan, Dr Fordyce, and Professor O'Rourke have also had a substantial intellectual contribution to the interpretation of the data.

8.8 Additional Material

8.8.1 Univariable screening

Descriptive statistics and herd-adjusted odds ratios and P values for 37 exposure variables that were eligible to enter the final logistic regression model as potential risk factors for risk of non-pregnancy in beef breeding females are presented in Table 8-5, Table 8-6 and Table 8-7.

Information relating to an additional eight candidate risk factors were not considered for inclusion in the multivariable modelling process due to having ≥40% incomplete records. These were:

- Hip height (≤125 cm / >125 to 140 cm / ≥140 cm),
- average liveweight gain between pregnancy diagnosis in the previous year and lactation assessment of the current year (<-250 gd-1/-250 to <350 gd-1 / ≥350 gd-1)
- liveweight recorded at the assessment of lactation in the current year (<450kg / ≥450kg)

The following candidate risk factors were not considered in the multivariate model building process as on candidate risk factor screening were found to be not statistically significant at ≤0.2.

- cumulative number of days where the maximum temperature reached 40oC during the estimated month of calving (<14 d/≥14 d),
- average dietary crude protein content of the pasture across the wet season (<7%/≥7%),
- provision of supplemental phosphorus (Not provided/provided),
- mustering inefficiency (<5% / 5 to <10% / ≥10%),
- age at which cows are culled-for-age (Not practiced / <10 y / ≥10 y)
- property pestivirus vaccination policy (Nil / Heifers only / Entire herd)

Table 8-5. Results of herd-adjusted logistic regression screening candidate herd management risk factors and non-pregnancy risk for all animal production years with valid non-pregnancy outcomes, with odds ratio (OR) 95% confidence interval (95% CI) of OR, and P value. Results restricted to only those risk factors with unconditional P values ≤0.2.

Variable	Raw observations		OR	95% CI of OR		p-value
	Non-pregnant (n)	Pregnant (n)		Lower	Upper	
Genotype						P<0.001
≥75% Bos indicus	10,153	36,285	Ref			
<75% Bos indicus	4,730	11,155	1.94	1.34	2.81	
Average size of management group at pregnancy diagnosis						P=0.01
<150	850	4,595	Ref			
≥150 to <400	7,123	22,489	1.79	1.14	2.81	
≥400	6,910	20,356	2.17	1.23	3.82	
Bull:Female ratio						P=0.02
<3:100	8,415	21,719	Ref			
≥3:100	6,468	25,721	1.58	1.07	2.31	
Bull selection policy						P=0.16
Some	1,983	7,664	Ref			
Little	7,745	19,856	1.66	0.98	2.80	
Most	4,649	17,530	1.27	0.77	2.11	
Annual bull management policy						P=0.03
Some	2,765	10,001	Ref			
Little	7,006	17,605	1.94	1.16	3.25	
Most	4,606	17,444	1.09	0.70	1.70	
Culling rate of breeding females						P=0.05
≥10 to <15%	3,064	14,660	Ref			
<10%	4,466	13,226	1.56	0.95	2.56	
≥15%	7,353	19,554	1.85	1.12	3.04	
Mating management						P<0.001
≤3m	2,138	12,448	Ref			
>3 to ≤7m	5,897	14,490	1.60	1.07	2.38	
>7m without seg	1,931	10,523	1.41	0.61	3.25	
>7m with seg	4,844	9,416	3.37	2.21	5.13	
Property management experience of manager						P=0.09
≥20 years	3,825	14,648	Ref			
≥10 to <20 years	1,462	4,921	1.32	0.73	2.39	
<10 years	9,596	27,871	1.57	1.05	2.36	
Botulinium property vaccination policy						P=0.002
Not vaccinated	4,179	15,987	Ref			
Vaccinated	10,572	30,541	1.77	1.23	2.55	
Leptospiros property vaccination policy						P=0.04
Vaccinated	4,944	12,719	Ref			
Not vaccinated	9,807	33,809	1.55	1.03	2.33	
Bulls vaccinated for BEF						P<0.001
Not vaccinated	1,828	10,128	Ref			
Vaccinated	12,923	36,400	2.35	1.59	3.48	

Table 8-6. Results of herd-adjusted logistic regression screening candidate animal attributes and risk factors and non-pregnancy risk for all animal production years with valid non-pregnancy outcomes, with odds ratio (OR) 95% confidence interval (95% CI) of OR, and P value. Results restricted to only those risk factors with unconditional P values ≤0.2.

Variable	Raw observations		OR	95% CI of OR		p-value
	Non-pregnant (n)	Pregnant (n)		Lower	Upper	
Cow-age class						P<0.001
Mature cows	8,911	31,149	Ref			
First-lactation cows	2,725	6,624	1.46	1.38	1.55	
Aged cows	3,247	9,667	1.11	1.06	1.17	
Estimated period of calving expressed as predicted window when the cow calved						P<0.001
Non-pregnant	886	7,400	Ref			
Jul-Sep	727	4,209	4.10	3.62	4.64	
Oct-Nov	2,741	9,999	5.00	4.56	5.47	
Dec-Jan	3,407	10,130	6.22	5.69	6.80	
Feb-Mar	1,863	2,463	12.88	11.61	14.28	
Apr-Jun	1,146	802	34.06	29.91	38.80	
Pregnant	1,853	2,318	14.27	12.85	15.86	
Failed to rear pregnancy	696	2,551	3.11	2.76	3.49	
BCS at the previous production cycle's pregnancy diagnosis muster						P<0.001
1 to 2	2053	5,013	Ref			
2.5	2107	5,098	1.31	1.21	1.42	
3	4,635	12,030	1.36	1.26	1.46	
3.5	2,385	8,542	1.35	1.24	1.46	
4 to 5	2,294	9,313	1.11	1.03	1.21	
BCS at branding orweaning muster						P<0.001
3.5	1,510	8,735	Ref			
1 to 2	2,475	2,680	4.45	4.08	4.85	
2.5	2,664	5,228	2.84	2.63	3.07	
3	2,865	12,122	1.39	1.29	1.49	
4 to 5	1,313	6,618	1.21	1.11	1.32	
BCS change between pregnancy diagnosis and branding or weaning muster						P<0.001
Gained	3,226	11,506	Ref			
Maintained or Lost	6,933	19,695	1.63	1.55	1.72	
Liveweight at the pregnancy diagnosis muster						P<0.001
≥500	1,197	7,441	Ref			
≥420 to <500	2,725	9,337	1.35	1.24	1.46	
<420 kg	5,655	12,081	1.50	1.37	1.63	

Abbreviations: BCS, Body condition score; FTR,

Table 8-7. Results of herd-adjusted logistic regression screening candidate nutritional and environmental risk factors and non-pregnancy risk for all animal production years with valid non-pregnancy outcomes, with odds ratio (OR) 95% confidence interval (95% CI) of OR, and P value. Results restricted to only those risk factors with unconditional P values ≤0.2.

Variable	Raw observations		OR	95% CI of OR		p-value
	Non-pregnant (n)	Pregnant (n)		Lower	Upper	
Country type						P<0.001
Southern Forest	1,565	8,330	Ref			
Central Forest	1,539	7,338	1.25	0.79	2.00	
Northern Downs	3,303	16,887	1.36	0.83	2.22	
Northern Forest	8,476	14,885	3.11	2.09	4.63	
Year observed						P<0.001
2010	8,101	27,586	Ref			
2009	499	2,018	1.19	1.06	1.33	
2011	6,283	17,836	1.28	1.23	1.34	
Wet season onset						P<0.001
Normal	6,821	21,921	Ref			
Early	7,491	22,950	1.31	1.20	1.44	
Late	396	1,880	1.17	0.95	1.43	
Wet season duration						P<0.001
Normal	9,168	23,611	Ref			
Short	1,505	6,738	1.76	1.58	1.95	
Long	4,035	16,402	1.27	1.20	1.35	
Average THI during month of calving						P<0.001
>72	10,449	27,588	Ref			
≤72	715	3,887	1.49	1.33	1.68	
No days THI ≥ 72 during month of calving						P<0.001
≥11 days	10,816	29,970	Ref			
≤10 days	348	1,505	1.91	1.64	2.22	
No days THI ≥ 79 during month of calving						P=0.002
≥15 days	8,206	20,137	Ref			
≤14 days	2,958	11,338	1.12	1.05	1.21	
No days maximum temperature ≥32^{o}C during month of calving						P<0.001
≥10 days	6,554	18,132	Ref			
<10 days	4,610	13,343	1.57	1.47	1.68	
Minimum dry season biomass						P=0.001
<2000 kg/ha	4,375	12,908	Ref			
≥2000 kg/ha	6,819	26,185	1.19	1.08	1.32	
Average dry season dietary crude protein						P<0.001
≥7%	1,670	6,632	Ref			
<7%	9,364	32,666	1.20	1.09	1.32	
Average dry season dry matter digestibility						P<0.001
≥55%	1,027	5,802	Ref			
<55%	10,007	33,496	1.33	1.20	1.46	
Average DMD:CP during dry season						P<0.001
<8:1	2,758	11,902	Ref			
≥8:1	8,276	27,396	1.43	1.18	1.72	
Average wet season dry matter digestibility						P<0.001
≥55%	8,178	32,317	Ref			
<55%	2,679	6,400	1.66	1.49	1.85	
Average DMD:CP during wet season						P=0.006
≥8:1	4,111	11,164	Ref			
<8:1	6,746	27,553	1.11	1.03	1.20	
Average FP:ME during wet season						P<0.001
≥500 mgP : 1 MJ ME	2,638	12,344	Ref			
<500 mgP : 1 MJ ME	8,219	26,373	1.60	1.46	1.75	

Table 8-7. Continued.

Variable	Raw observations: Non-pregnant (n)	Raw observations: Pregnant (n)	OR	95% CI of OR: Lower	95% CI of OR: Upper	p-value
Provision of supplemental nitrogen						P<0.001
Not provided	11,651	31,445	Ref			
Provided	3,232	15,995	1.88	1.30	2.70	
Provision of supplemental phosphorus						0.35
Not provided	5,859	21,369	Ref			
Provided	9,024	26,071	1.20	0.82	1.77	

Abbreviations: THI, temperature humidity index; FP:ME, Ratio of faecal phosphorus to metabolisable energy; DMD:CP, ratio of dry matter digestibility to dietary crude protein

8.8.2 Model performance

Distributions of observed and expected frequencies differed significantly (*P*<0.001) when expected frequencies were based on the fixed part of the final model, suggesting that the fixed part of the model was poorly calibrated. The fixed part of final multivariable model fitted the data only partially well with more than expected cases of non-pregnancy at lower probabilities (Table 8-8).

Table 8-8. Observed (Obs) and expected (Exp) frequencies by decile of risk using estimated probabilities from the fixed part of the final model of non-pregnancy.

Decile	Probability	Reproductive outcome: Non-pregnant — Not pregnant: Obs	Not pregnant: Exp	Pregnant: Obs	Pregnant: Exp	Total
1	0.037	263	132	3,328	3,459	3,591
2	0.057	222	164	2,668	2,726	2,890
3	0.073	320	237	2,942	3,025	3,262
4	0.095	367	310	2,893	2,950	3,260
5	0.124	468	399	2,755	2,824	3,223
6	0.167	572	563	2,794	2,803	3,366
7	0.215	607	665	2,487	2,429	3,094
8	0.297	1,037	967	2,215	2,285	3,252
9	0.452	1,401	1,454	1,818	1,765	3,219
10	0.677	2,134	2,182	1,091	1,043	3,225

There were 4,932 standardised residuals ($\Delta\beta$) greater than 3 or less than –3, equivalent to 15.2% of all observations in the dataset. The highest observed standardised residual was 12.56. Elevated $\Delta\chi2$ statistics (greater than 27) were reported for 1297 cases and no common covariate patterns were found. The final analysis was attempted to be repeated after removing the 1297 cases with the largest $\Delta\chi2$ statistics. However, the resulting model would not converge and thus, the coefficients could not be inspected and compared to the original model, as a result no observations were removed from the dataset (Dohoo *et al.* 2009).

The final model had an acceptable ability to discriminate between those cows that were positive for non-pregnancy to those that were not, with 69.9% correct predictions. Using a probability cut point of 0.192, determined by inspection of a graph of the sensitivity and specificity versus the probability cut points (Figure 8-1), classification statistics were calculated and are presented in Table 8-9. Sensitivity was high (>0.90) at low probability cut points (<0.1) while, specificity was high (>0.90) at probability cut points >0.5 (Figure 8-1). The area under the receiver operating characteristic curve was estimated as 0.76 (95% CI, 0.76-0.77) (Figure 8-2).

Table 8-9. Classification for the final model based on the probability cutpoint 0.192.

Observed non-pregnancy	Classified (predicted) status		Total
	pr(non-preg)<0.192	pr(non-preg)≥0.192	
0	17388	7603	24991
1	2220	5171	7391
Total	19608	12774	32382

Sensitivity	16.0%
Specificity	23.5%
Positive Predictive value	69.6%
Negative Predictive value	70.0%
Percent correct predictions	69.7%

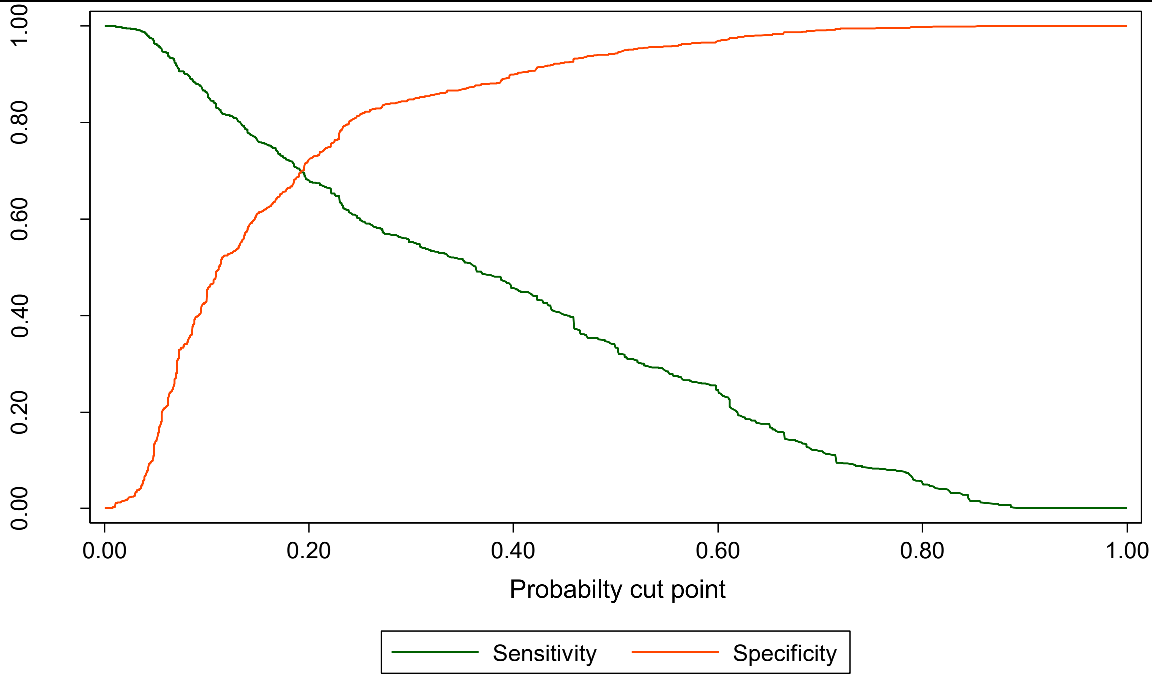

Figure 8-1. Sensitivity and specificity of the final model.

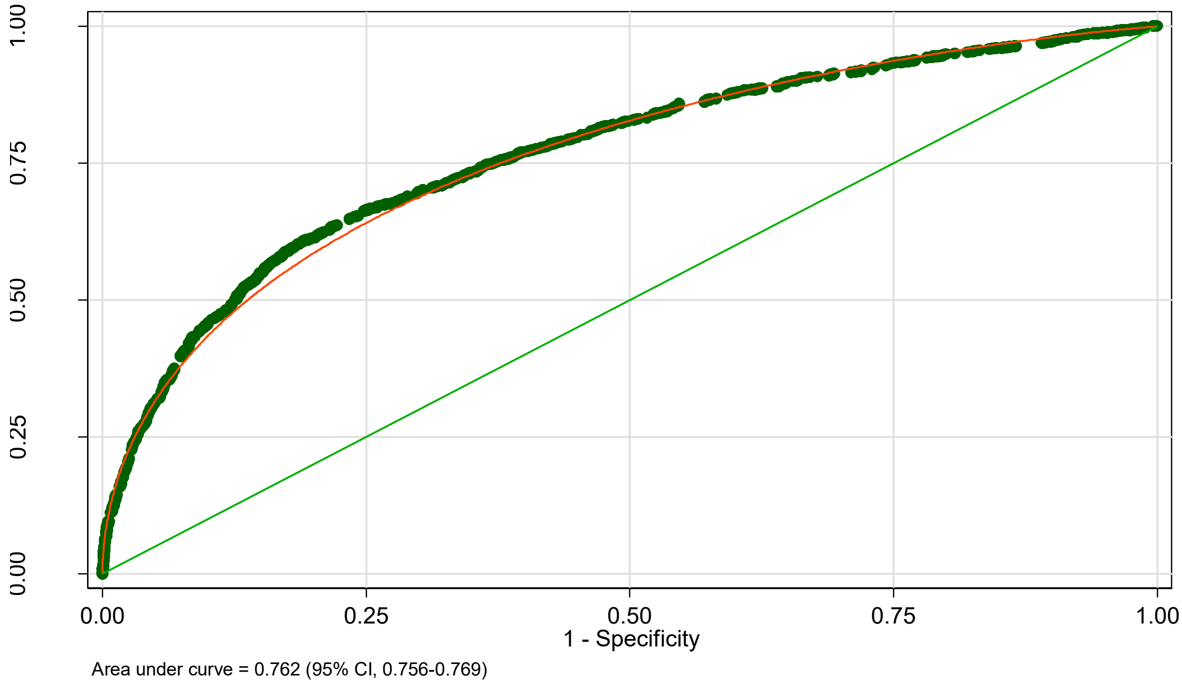

Figure 8-2. Area under the receiver operating characteristic curve using only the fixed part of the final model.

Chapter 9 Risk factors affecting reproductive losses between confirmed pregnancy and weaning in north Australian commercial beef cattle herds

9.1 Abstract.

A prospective epidemiological study was conducted in a selected population of commercial beef breeding herds in northern Australia. Approximately 78,000 cattle managed in 78 herds were monitored for 3 to 4 years. The impact of identified major risk factors for foetal and calf loss between confirmed pregnancy and weaning were estimated in a multivariable model which drew on data representing 23,166 pregnancies and 55 herds. The country types assigned were Southern Forest, Central Forest, Northern Downs and Northern Forest within this mostly dry tropical environment. Median foetal and calf loss was 9.5% with large variation across all of northern Australia. Achievable levels appeared to be <10% for Northern Forest herds, and <5% for beef herds in other country types.

Where the risk of phosphorus deficiency was high, foetal and calf loss was generally higher than where the risk of phosphorus deficiency was low ($P<0.001$). The difference in foetal and calf loss was 8 percentage points when body condition score was <2.5 (1-5 scale). High phosphorus deficiency risk was associated with 10 percentage point higher foetal and calf loss in the Central and Northern Forest than in the Southern Forest ($P<0.01$), whereas low risk of deficiency resulted in no effect of country type on losses. When the temperature-humidity index (THI) exceeded 79 for at least two weeks during the month of expected calving, calf losses were increased by 4-7 percentage points ($P<0.01$), except in the Northern Forest. If THI was low, foetal and calf losses were 9 percentage points higher in the Northern Forest than in either the Northern Downs or Southern Forest ($P<0.05$). Calf loss from cows in their first lactation was increased by 9 percentage points when mustered around calving ($P<0.001$). As well, foetal and calf losses were 9 percentage points higher where mustering efficiency was <90% compared to where it was >90%. Confirmed pregnancy to weaning loss was 8 percentage points lower in second-lactation and aged cows if they lactated in the previous year, indicating partial repeatability. Tall cows lost 4 percentage points more pregnancies before weaning than short cows, though there is no obvious reason for this, it is speculated that tall cows would be more likely to lose condition than smaller cows under conditions of environmental stress.

Several group-level factors were back fitted to the final model to predict their impact on foetal and calf loss. Where managers considered wild dogs were adversely impacting on herd productivity, whether control was being attempted or not, a trend occurred for foetal and calf loss to be 4-5% higher than where wild dogs were not considered a problem. Inadequate dietary protein during the dry season was associated with 4.2 percentage point higher loss compared to that for females with

adequate dry season dietary protein. In groups where there was a high prevalence of recent bovine viral diarrhoea virus infection there was 9 percentage points higher foetal and calf loss than in groups with a low prevalence of recent infection. In groups where the prevalence of samples positive for antibodies to *C. fetus* sp. *veneralis* was high, foetal and calf loss was 7 percentage points higher than in groups where the antibody prevalence was low to moderate (p=0.02). No significant association occurred between foetal and calf loss and prevalence of antibody against either neosporosis, leptospirosis, bovine ephemeral fever or *Coxiella burnetti* , despite some trends suggesting potential effects, for example, a 3 percentage points reduction in losses when vaccination against leptospirosis was used.

The major conclusion from this research is that a wide range of risk factors have large and additive effects on foetal and calf loss in northern Australia. The combined effects of environmental, nutritional and management risk factors were much greater, collectively up to 30-40%, and more consistent than that due to either endemic infectious diseases or animal factors. It is suggested that remedial action for the effect of non-infectious risk factors should target milk delivery to neonatal calves.

9.2 Introduction

Recently, a comprehensive review (Burns *et al.* 2010) and several other publications demonstrated high and variable foetal and calf loss in north Australian beef herds (Table 9-1) across four country types. The fertile soil areas in central and south-east Queensland were differentiated into those predominated by eucalypts (Southern Forest) and *Acacia spp*. (Central Forest). In northern and western areas, treeless black-soil grasslands (Northern Downs) were differentiated from forested areas with low-fertility soils (Northern Forest). Two thirds of post-calving loss occurs within a week of birth (Bunter *et al.* 2013). Burns *et al.* (2010) were unable to identify achievable levels of loss for much of northern Australia. Bunter *et al.* (2013) reported that reproductive wastage is increased by: 8 percentage points when birth weight is <1 SD below the population mean; 20 percentage points in cows with bottle teats, confirming a previous report by Holroyd (1987); 6 percentage points when udder score is 5 (1-5 scale); up to 25 percentage points due to Vitamin A deficiency after consecutive low-rainfall years on treeless plains; and, 2 percentage points following dehorning. Fordyce *et al.* (2009) reported 5-10 percentage point higher loss due to dystocia when calving at 2 years without strategic nutritional support. Burns *et al.* (2010) reported that, though there are many endemic infectious diseases with the potential to cause foetal and calf loss, there is very limited data confirming effects; eg, Fordyce *et al.* (2013b) were unable to show any impact of

Neospora caninum on losses. The review of Burns *et al.* (2010) reported occasional calf loss associated with weather extremes in northern Australia, but not consistent effects. Even in the most comprehensive studies such as by Holroyd (1987), reasons for the majority of losses in northern Australia have remained "unknown", despite intensive observations over many years. Most of the reported research has been conducted in controlled research station environments, and the situation within commercial environments is even less apparent.

Table 9-1. Recent reports of foetal and calf loss in north Australian beef cattle.

Time of loss	Southern forest	Central forest	Northern downs	Northern forest	Reference
Prenatal	0-9%	0-13%	5-8%	1-12%	Burns *et al.* (2010)
Perinatal		3-10%	2-12%	3-8%	Burns *et al.* (2010)
	2%	3%	12%	3%	Bunter *et al.* (2013)
Postnatal		0-5%	9-10%	3-16%	Burns *et al.* (2010)
	2%	4%	6%	5%	Bunter *et al.* (2013)
Pregnancy to weaning			12-39%		Schatz and Hearnden (2008)
		7-18%	21%	3-31%	Burns *et al.* (2010)
				0-29%	Fordyce *et al.* (2009)
			13%	8%	Fordyce *et al.* (2013b)

The loss of a foetus or calf reduces lactation rate and live weight production per cow, especially when associated with cow mortality. A 1 percentage point reduction in lactation rate is associated with a reduction in gross margin per adult equivalent (450 kg) of approximately AUD$1 (Niethe and Holmes 2008). In a typical business that can sustain 3,000 adult equivalents, management changes to reduce reproductive wastage by 5 percentage points and costing up to AUD$15,000 are likely to be viable. Specific opportunities to remediate reproductive wastage are indicated by the risk factors associated with loss, but these have not previously been identified for commercial herds in this region.

As a progression from the situation described above, a large prospective population-based epidemiological study involving 78 commercial beef herds across northern Australia (McGowan *et al.* 2014) was conducted to answer a number of questions, one of which was: Which of eighty-three region-, property-, management group-, and animal-level risk factors measured are associated with pregnant females failing to wean their calf? This research has provided the opportunity to quantify foetal and calf loss occurring in herds. Cow mortality, which has a high association with foetal and calf loss (Fordyce *et al.* 1990), and which has recently been reported to range between 0-28% in northern forest areas (Fordyce *et al.* 1990; Henderson *et al.* 2013), will be considered elsewhere as a risk factor for reproductive wastage.

9.3 Materials and methods

9.3.1 Ethics

The University of Queensland Animal Ethics Committee approved the conduct of this research per certificates SVS/756/08/MLA and SVS/729/07/MLA.

9.3.2 Environment, cattle and management

Northern Australia is transected by the Tropic of Capricorn. Summer temperatures are high. Winters are warm in the north and cooler in the south. Frosts are common in inland areas south of the Tropic of Capricorn. Australia is relatively dry with 50% of the country having a median rainfall of less than 300 mm per year and 80% receives less than 600 mm (Anon 2014). A north Australian 'wet' season, when most rain falls and grass grows, generally occurs from December through April. The remainder of the year is called the 'dry' season. Annual average evaporation exceeds 2 metres and is double this in some situations. Four major country types were distinguished as described above. Properties were assigned to one of four broad country types following a subjective assessment of the production potential (annual yearling growth) of the grazing land and cross-referencing with pasture and vegetation descriptions reported by the herd managers. Estimated median annual yearling growth for the Northern Forest, Northern Downs, Central Forest and Southern Forest was calculated as 100kg, 170kg, 180kg and 200kg, respectively.

Of the approximately 26 million Australian beef cattle, over half are located in the northern region and 45% in Queensland (Anon 2012). A large range in breeds occurs and the distribution of *Bos indicus* level for 56,994 cattle within the project is shown in Figure 9-1. For this study, the outcome was studied following confirmed pregnancy in 23,166 cows of all ages from 55 herds selected as having a full data complement on prevailing risk factors (Table 9-2). Mature cow live weight (5+ years of age; non-pregnant; body condition score 3 on a 1-5 scale) in commercial beef cattle of northern Australia is typically in the vicinity of 500 kg, with first-pregnancy females aged 2.5 years being an average 50-100 kg lighter.

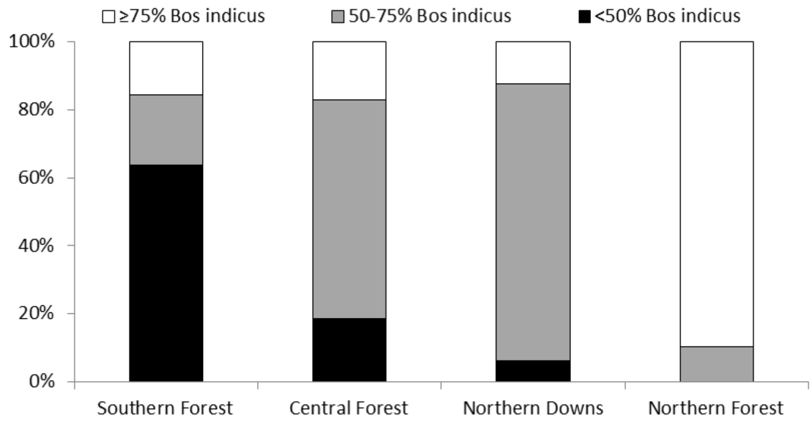

Figure 9-1. Prevalence of Bos indicus level in north Australian beef cattle

Table 9-2. Cases included in the analysis

Country Type	No. of Groups	Cows per group Median	Lowest	Highest	Total cows
Southern Forest	15	287	72	1036	5,588
Central Forest	12	423	72	1111	5,460
Northern Downs	10	495	291	1936	6,705
Northern Forest	18	267	59	688	5,413
Total	55	333	59	1936	23,166

Low-input ("extensive") management is a feature of beef production in northern Australia. Cattle diets are almost exclusively pasture. Stocking rates are low and in some areas are as low as one cow per 150ha (Tothill and Gillies 1992). Management groups of 300 to 1,000 cattle are common. The majority of cows are continuously mated with peak calving occurring late in the calendar year. Seasonal mating is usually between 3 and 7 months where suitable bull-control infrastructure is available. Cattle handling for husbandry is infrequent and is typically twice annually in April-July and August-September (Bortolussi *et al.* 2005a). Mustering using aircraft and on-ground vehicle support is used on about 50% of properties.

9.3.3 Animal measurements

Pregnant animals were identified and foetal age determined by rectal palpation by an accredited veterinarian (National Pregnancy Diagnosis Scheme, Australian Cattle Veterinarians) in four consecutive years (2008-2011) at or near the last annual weaning muster in June-October. Breed and age of cows were recorded. Live weight and height at the hips was recorded at this time. At each muster for branding, weaning and pregnancy diagnoses in the year following confirmed pregnancy, lactation status and body condition score were assessed.

Females were recorded as having experienced foetal and calf loss if they were recorded as not lactating at the first muster after the expected calving date (as calculated from foetal ageing and using a gestation period of 287 days), if this muster occurred more than one month after calving and they were not subsequently recorded as lactating. Cows lactating after their expected calving date were recorded as not experiencing foetal and calf loss. It is recognised that this measure does not include calf loss between branding and weaning, nor losses associated with cow mortality.

In 2009 and 2011, serum samples (both musters) and matching vaginal mucus samples (at pregnancy diagnoses) were collected from 30 randomly-selected cows within each management group. All samples were stored frozen. Subsequent serology measured antibody against Bovine Viral Diarrhoea Virus (AGID antibody; McGowan *et al.* (1993b)), *Neospora caninum* (ELISA antibody; Björkman *et al.* (1997)), *Leptospira spp* . (MAT antibody; Smith *et al.* (1994)), Bovine Ephemeral Fever (VNT antibody; Cybinski (1987)) and *Coxiella burnetti* (ELISA antibody; Cooper *et al.* (2011)). IgA antibody against *Campylobacter fetus* sp.*veneralis; (Hum et al. 1994)*) was measured in vaginal mucus. These assays provided management group-level prevalence of antibody, and in the case of BVDV and Leptospirosis, provided an indication of incidence of recent infection.

9.3.4 Other risk factor measurements

A large number of management group-level measures of potential risk factors were recorded including nitrogen and phosphorus supplementation, weaning age, pest presence and control, mustering methods, vaccines given, and bull to female ratios.

All weather conditions were measured using interpolated data (Bureau of Meteorology, Australia). Start of the wet season was defined as having at least 50 mm over 14 days after 01 September. Temperature humidity index was calculated as 0.8T-RH(T-14.4)+46.4 (Hahn *et al.* 2009), where T = ambient temperature (^{O}C) and RH = Relative humidity. Pasture assessments each 3 months included standing pasture/ha and diet digestibility (DMD) and crude protein (CP) estimated from near-infrared reflectance spectrometry (NIRS) of faecal samples (Dixon and Coates 2005) collected from management groups. The threshold for protein adequacy was a DMD:CP ratio of 8:1. The measure of phosphorus adequacy (Jackson *et al.* 2012) used was the ratio of faecal phosphorus (mg/kg FP; wet chemistry measure) to dietary metabolisable energy (MJ ME/kg from NIRS measures: 0.172*DMD-1.707). Land condition was assessed on an A-D scale (Chilcott *et al.* 2003). Each paddock was mapped to calculate the proportion and area within 2.5 km of permanent water.

9.3.5 Statistical analyses

All analyses were conducted in Stata, version 12 (www.stata.com). Multivariable models were built using logistic regression for foetal and calf loss coded using a binary notation, where 0 denoted successfully reared a calf and 1 denoted failed to rear a calf. Models were built using a manual stepwise approach (Dohoo *et al.* 2009). Variables were screened one at a time and retained for consideration in the final multivariable model if the univariable screening p-value was <0.20. Correlation matrices of all candidate explanatory variables were used to identify explanatory variables that were highly correlated (r>0.9) and where this occurred only one of the correlated variables was considered in the multivariable model.

The assumption of linearity of continuous variables in the logit were evaluated by inspecting partial residual graphs following herd-adjusted logistic regression models fitting the continuous variables as the main effect of non-pregnancy using Stata's –lpartr- command (Hilbe 2009). Continuous variables that appeared to fail the assumption of linearity were categorised into two or more categories. Wherever possible, continuous variables were categorised using established threshold values. However, in some cases, where these were not found to be discriminatory, cut points were determined by changes in the slope of cubic splines fitted to partial residual plots.

The data had a natural hierarchical structure with 3 levels; represented by an annual production cycle for an individual animal, within animals (level 1), within properties (level 2), within country-type (level 3). Intercept-only models with up to three nested random effects were explored. As there were only minimal individual animals (31.3%) contributing more than one production year of data, final models were simplified to property being incorporated as a random effect and country-type included as a main effect.

The model building process started with all candidate animal-level explanatory variables being added to the starting model and non-significant variables dropped one at a time, starting with the non-significant variable with the highest p-value. This process was continued until only significant variables remained in an interim, animal-level model. Explanatory variables measured at the management group or property level were then considered for inclusion in the model and retained if they were associated with a significant p-value, creating a candidate main effects model that included animal and management group level variables.

Biologically plausible two-way interactions were then considered and retained if they were associated with a significant p-value and an interpretable association based on assessment of marginal means and plots of effects. Country type was forced into models and two-way interactions considered between country type and other explanatory factors, because of specific interest in the effects represented by country type.

An appraisal of effects of potential confounding variables was completed by individually including each variable into the candidate model and assessing changes in the measure of association for statistically significant variables. Confounding was considered important when odds ratios for statistically significant variables changed by >20-30% (Dohoo *et al.* 2009) and the variable was included in the final main effects model.

All logistic regression models incorporated a random effect coding for property identity to adjust for correlations between cows within the same property. Model checking involved generation of summary measures of goodness-of-fit and identifying any specific observations that did not fit the model or were having undue influence on the model (Dohoo *et al.* 2009).

Variance partitioning was explored by considering an intercept-only model with up to three nested random effects represented by observations within animals (level 1), within properties (level 2), within country type (level 3), to produce starting estimates of variance at each of the three hierarchical levels in the dataset.

The significance of the differences between levels within a factor was assessed using p-values for pairwise odds ratios and the magnitude of the differences quantified by marginal means expressed as percentages and associated confidence intervals.

Associations between selected additional explanatory variables were explored by back-fitting them one at a time to the final multivariable model, ie, adding a selected explanatory variable, regardless of whether the added explanatory variable was previously significant or not. The resulting model output was then used to generate estimates of predicted outcomes for the levels of the added variable of interest and these estimates are adjusted for the effects of all of the other terms in the final model. We recognise the caution required in interpreting the findings.

Following fitting the final multivariable model, average marginal effects of risk factors were computed using Stata's -margins- postestimation command. Differences between estimated marginal means across levels of each risk factor or interaction term were estimated and statistically compared using nonlinear combinations of estimators and pairwise comparisons, respectively.

9.4 Results

9.4.1 Description of study population

The starting dataset contained observations from 75 herds relating to 46,065 animal-production years of data. An average, an individual animal contributed 1.37 (range 1-3) annual production cycles that the outcome of foetal and calf loss could ascribed.

The median foetal and calf loss for groups was 9.5%, with large variation within each country type (Figure 9-2). In addition to the distribution shown, three Northern Forest herds and one herd each in the Central and Southern Forests experienced losses in one year of between 38% and 61%.

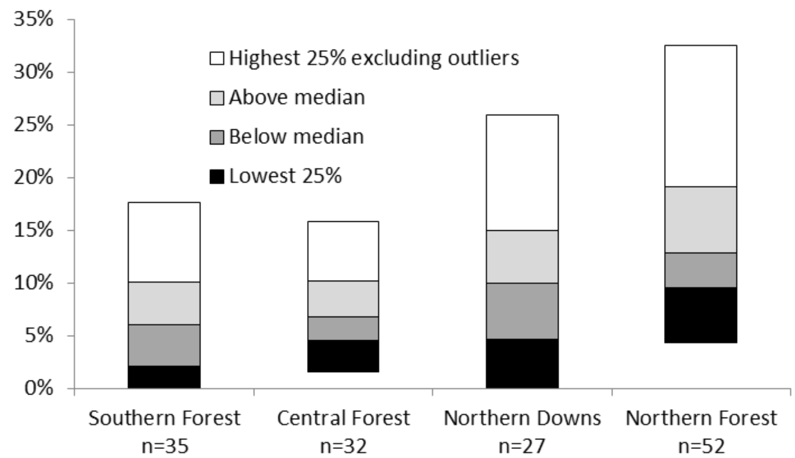

Figure 9-2. Distribution of foetal and calf loss within country type for north Australian beef herds: Number of management group-years is given

9.4.2 Univariate associations

The candidate risk factors that were considered during univariate screening and progressed into the multivariable modelling process are presented in Table 9-3 (Results of herd-adjusted logistic regression models to screen candidate risk factors by including each candidate risk factor as a single main effect term is presented as additional material in Section 9.7.1). Two risk factors ('body condition score change between pregnancy diagnosis and branding or weaning muster' and 'successfully raised confirmed pregnancy in previous reproductive cycle') did not progress into the multivariable modelling process due to having ≥40% incomplete records. A further eleven risk factors were not considered in the multivariable model building process as they were not significant using the liberal p-value of 0.2 (Dohoo *et al.* 2009) and included: Bull:Female ratio, body condition score at the pregnancy diagnosis muster, timing of wet season onset, average DMD:CP during the dry season, provision of supplemental nitrogen, provision of supplemental phosphorus, average wet season dietary crude protein, average wet season dry matter digestibility, and predominant class of animal at turnoff.

Table 9-3. List of cow- and herd-level risk factors for cows at the risk of non-pregnancy that were considered during unconditional assessment and were considered in the multivariable model building process.

Risk Factor	
Herd management	
Property management experience of manager	Culling age of breeding females
Reported size of the herd	Mating management
Average size of management group at pregnancy diagnosis	Botulinium property vaccination policy
Bull:Female ratio	Leptospirosis property vaccination policy
Bull selection policy	Bulls vaccinated for BEF
Impact of wild dog s	Annual bull management policy
Environment	
Year observed	Cumulative number of days temperature humidity index exceeded 71 during month of calving
Wet season onset	Cumulative number of days temperature humidity index exceeded 79 during month of calving
Wet season duration	Average temperature humidity index during month of calving
Cumulative number of days maximum temperature exceeded 32°C during month of calving	
Nutrition	
Average dry season crude protein	Average wet season crude protein
Average dry season DMD	Average wet season dry matter digestibility
Average ratio DMD:CP during dry season	Average ratio dry matter digestibility to crude protein during wet season
Provision of supplemental nitrogen	Average ratio faecal phosphorus to metabolisable energy during wet season
Provision of supplemental phosphorus	
Area of paddock around time of calving	
Proportion of paddock within 2.5km from permanent water	
Animal	
Cow-age class	Body condition score at the branding or weaning muster
Estimated period of calving expressed as predicted window when the cow calved	Body condition score change between pregnancy diagnosis and branding or weaning muster
Body condition score at the pregnancy diagnosis muster	

9.4.3 Multivariable model results

The final model included data representing 23,166 animal production years from 55 herds; 49.7% of animal production years and 29.5% of herds with valid entries for confirmed pregnancy to weaning loss were not represented in the final model because of missing values for one or more risk factors. On average, each herd and individual cow contributed information relating to 421.2 (range 59-1936) and 1.59 (range 1-3) animal production years, respectively in the final model. Due to the minimal replication within animals models were run with one level of random effects, property, and country type was included as a fixed effect. In the final model (Table 9-4) the proportion of the total variance within our data that was explained by the variance between herds was 18.5%, of which 33.9% was estimated to be explained using an intercept only final model. Fixed effects in the final multivariable model explained 7.6% of the variation in foetal and calf loss between pregnancy diagnosis and weaning.

The odds ratios, significance and confidence intervals for variables in the selected model are presented in Table 9-4. Alternative valid models that were able to explain similar levels of variance in foetal and calf loss were investigated. Selection of the final model was on the basis of having the most biologically-plausible outcomes, and included factors that provided the best opportunity for intervention to reduce losses. The final model included wet season FP:ME ratio (in preference to a combination of leptospirosis vaccination and wild dog activity) and body condition score at pregnancy diagnosis (in preference to dry season DMD:CP ratio).

The final model had an acceptable ability to discriminate between those cows that were positive for confirmed pregnancy to weaning loss and those that were not, with 60.8% correct predictions while the area under the receiver operating curve was 0.64 (95% CI, 0.63-0.65). Sensitivity was high (>0.90) at very low probability cut points (<0.05) while, specificity was high (>0.90) at probability cut points >0.2. The fixed part of final multivariable model fitted the data only partially well with fewer cases of non-pregnancy than expected at lower probabilities. The *P* value for the Hosmer-Lemeshow goodness-of-fit statistic was <0.001, indicating a poor fit. Potential outlier and influential data points were evaluated and an inspection of the covariate values revealed that all values were plausible. As there are no grounds for dropping these observations from the dataset the original random effects model with 23,166 observations was retained.

Table 9-4. Adjusted odds rations, 95% confidence intervals and P values from a multivariable logistic regression model of risk factors for probability of foetal and calf loss between confirmed pregnancy and weaning in surviving cows. Data drawn from 23,166 animal production years from 55 herds.

Variable	Coefficient	SE	Adjusted OR	95% CI of OR Lower	Upper	*P* value[a]
Country type						**0.2**
Southern Forest	0.00	0.36	1.0	0.49	2.01	0.99
Central Forest	-0.05	0.37	0.95	0.46	1.97	0.90
Northern Downs	Ref					
Northern Forest	0.67	0.41	1.95	0.87	4.38	0.11
Lactated previous reproductive cycle						**<0.0001**
Yes	Ref					
No	0.32	0.08	1.37	1.18	1.59	<0.01
Hip height						**<0.01**
<125 cm	-0.17	0.12	0.84	0.67	1.07	0.15
125-140 cm	Ref					
>140 cm	0.16	0.06	1.17	1.05	1.3	<0.01
BCS at the pregnancy diagnosis muster						**<0.0001**
1-2	-0.35	0.20	0.71	0.48	1.04	0.08
2.5	0.16	0.14	1.17	0.89	1.55	0.27
3.0	Ref					
3.5	0.22	0.12	1.25	0.99	1.57	0.06
4-5	-0.32	0.13	0.72	0.56	0.93	0.01
Cow-age class cohort						**0.11**
1st preg	0.19	0.09	1.21	1.02	1.44	0.03
2nd preg	0.09	0.09	1.09	0.92	1.3	0.30
Mature	Ref					
>9 years	0.13	0.09	0.95	1.35	1.14	0.15
Mustered within 2 months of calving						**0.02**
No	Ref					
Yes	0.23	0.10	1.26	1.04	1.54	0.02
Temp-humidity index >79 in calving month						**<0.01**
<15 days	Ref					Ref
≥15 days	0.63	0.16	1.89	1.39	2.56	1.89
Average ratio of FP:ME during the wet season						**0.50**
<500gP:MJME	0.12	0.17	1.13	0.8	1.58	0.50
≥500gP:MJME	Ref					
Mustering efficiency						**0.03**
>90%	Ref					Ref
<90%	0.79	0.36	2.2	1.08	4.47	2.2
Interaction: BCS at the pregnancy diagnosis muster x Average ratio of FP:ME during the wet season						**<0.0001**
1-2: <500	0.41	0.22	1.51	0.98	2.34	0.06
2.5: <500	-0.12	0.17	0.89	0.64	1.25	0.50
3.5: <500	-0.45	0.14	0.64	0.48	0.84	<0.01
4-5: <500	0.13	0.15	1.14	0.85	1.54	0.37
Interaction: Country type x Average ratio of FP:ME during wet season						**<0.0001**
Southern Forest: <500	-0.19	0.21	0.83	0.55	1.24	0.36
Central Forest: <500	0.72	0.20	2.06	1.38	3.06	<0.01
Northern Forest: <500	0.20	0.27	1.23	0.73	2.07	0.44
Interaction: Cow-age class x Mustered within a month of calving						**<0.0001**
1st preg: Yes	0.40	0.17	1.49	1.07	2.09	0.02
2nd preg: Yes	-0.37	0.24	0.69	0.43	1.11	0.13
>9 years: Yes	-0.06	0.23	0.94	0.6	1.47	0.78

Table 9-4. Continued.

Variable	Coefficient	SE	Adjusted OR	95% CI of OR Lower	Upper	*P* value[a]
Interaction: Country type x Calving month THI >79						**<0.01**
Southern Forest: >15 d	-0.20	0.22	0.82	0.53	1.27	0.38
Central Forest: >15 d	-0.21	0.20	0.81	0.55	1.19	0.28
Northern Forest: >15 d	-0.69	0.20	0.5	0.34	0.74	<0.01
Intercept	-3.08	0.31				**<0.0001**
Random effect				**95% CI**		
				Lower	**Upper**	
Level 2 (property)			0.70	0.57	0.87	
rho (ICC)			0.13	0.09	0.19	

Abbreviations: BCS, body condition score; FP:ME, ratio of faecal phosphorus to metabolisable energy; DMD:CP, Ratio of dry matter digestibility to dietary crude protein;
*Bold values are generalised Wald-test P values; others are Wald-test values.

Confirmed pregnancy to weaning loss was 3.6 percentage points lower in cows that lactated than those that did not lactate in the previous year (P<0.001; Table 9-4 and Table 9-5). The latter included cows diagnosed non-pregnant and those that lost a foetus or calf before lactation assessment after being diagnosed pregnant. All first-lactation cows did not have a previous reproductive cycle and were analysed as being non-lactating. Therefore, an interaction term was added to the final model to confirm this effect is not solely due to heifers. The effect was significant and losses were 7.6 percentage points lower in second-lactation and aged cows if they lactated in the previous year.

Tall cows lost on average 3.7 percentage points more pregnancies before weaning than short cows (P<0.01; Table 9-4 and Table 9-5), with moderate-height cows intermediate.

Where the risk of phosphorus deficiency was low (≥500 FP:ME ratio), overall foetal and calf loss was 3.4 percentage points lower than where the risk of phosphorus deficiency was high (P<0.001; Table 9 4 andTable 9-5). The difference was 8 percentage points when body condition score was <2.5. However, low risk of phosphorus deficiency was associated with 2 percentage point higher calf loss in cows with body condition score of 3.5. Where FP:ME ratio was low, foetal and calf loss was an average of 10 percentage points higher in the Central and Northern Forest, in comparison to that in the Southern Forest (P<0.01). In contrast, where FP:ME ratio was high, there was no significant effect of country type on losses. Only in the Central Forest was there a significant difference in foetal and calf loss between groups grazing paddocks with low or high FP:ME ratios (10 percentage points; P<0.001; Table 9 4 and Table 9-5).

Losses in situations where mustering efficiency was <90% were 9 percentage points higher (2.2 times more likely; P=0.029; Table 9 4 and Table 9-5) than where mustering efficiency was >90 percentage points. It is unclear whether this was related to the mustering process or whether this factor is a surrogate for the class of country and or prevailing weather that causes low mustering efficiency, or if it is a reflection of overall management.

When cows were not mustered around calving, foetal and calf loss was 1.3 percentage points higher in first-lactation cows than in older cows (P<0.05). In mature cows, foetal and calf loss was increased by 2.5 percentage points if they were mustered around calving (P=0.02), with a similar but non-significant effect observed for aged cows. However, loss from cows in their first lactation was increased by 9 percentage points when mustered around calving (P<0.001; Table 9-4 and Table 9-5).

When the temperature-humidity index (THI) exceeded 79 for at least two weeks during the month of expected calving there were no significant differences between country types. However, calf losses under lower THI conditions were reduced by 3.9-6.7 percentage points (P<0.01; Table 9-4 and Table 9-5), except in the Northern Forest where there was no effect of THI. If THI was not >79 for at least two weeks in the expected calving month, foetal and calf losses were 9 percentage points higher in the Northern Forest than in either the Northern Downs or Southern Forest (P<0.05); losses in the Central Forest were intermediate and not significantly different from other country types.

Several group-level factors were back fitted to the final model to predict their impact on foetal and calf loss. Where managers considered wild dogs were adversely impacting on herd productivity, whether control was being attempted or not, a trend occurred for foetal and calf loss to be 4-5 percentage points higher than where wild dogs were not considered to be adversely affecting productivity. For management groups where wild dogs were considered to be adversely affecting herd productivity Level of control had no significant impact on calf loss.

Table 9-5. Predicted means (%) for significant effects on foetal and calf loss in north Australian beef cows

Variable	Levels		Mean	95% Confidence interval Lower	Upper
Lactated previous reproductive cycle	No		15.0	10.0	19.9
	Yes		11.4	7.5	15.2
Hip height	≤ 125cm		11.3	7.0	15.6
	125-140cm		13.1	8.9	17.4
	> 140cm		15.0	10.2	19.9
Mustering efficiency	>90%		9.2	7.2	11.2
	≤90%		18.2	7.9	28.6
Interaction: Body condition score a foetal ageing * Wet season FP:ME ratio	2.0	< 500	16.6	10.8	22.4
	2.0	≥ 500	8.9	4.7	13.0
	2.5	< 500	16.2	10.7	21.8
	2.5	≥ 500	13.9	8.6	19.2
	3.0	< 500	15.7	10.5	20.8
	3.0	≥ 500	12.1	7.6	16.5
	3.5	< 500	12.9	8.4	17.3
	3.5	≥ 500	14.6	9.5	19.8
	4.0	< 500	13.3	8.8	17.9
	4.0	≥ 500	9.0	5.5	12.5
Interaction: Country type * Wet season FP:ME ratio	Southern Forest	< 500	9.6	5.2	14.0
	Southern Forest	≥ 500	10.3	5.8	14.8
	Central Forest	< 500	20.1	10.9	29.4
	Central Forest	≥ 500	9.9	4.8	14.9
	Northern Downs	< 500	12.5	5.9	19.1
	Northern Downs	≥ 500	11.3	5.0	17.7
	Northern Forest	< 500	19.5	12.7	26.3
	Northern Forest	≥ 500	15.0	7.6	22.4
Interaction: Cow age * Mustered within a month of calving	1st pregnancy	No	12.8	8.5	17.2
	1st pregnancy	Yes	21.7	13.9	29.4
	2nd pregnancy	No	11.7	7.6	15.8
	2nd pregnancy	Yes	10.4	5.2	15.5
	Mature	No	10.8	7.2	14.5
	Mature	Yes	13.3	8.6	18.0
	>9 years	No	12.1	7.8	16.5
	>9 years	Yes	14.0	7.6	20.5
Interaction: Country type * days temperature-humidity index >79 in calving month	Southern Forest	< 15	8.2	4.5	11.8
	Southern Forest	≥ 15	12.1	6.6	17.6
	Central Forest	< 15	11.9	5.9	17.8
	Central Forest	≥ 15	17.0	9.0	25.1
	Northern Downs	< 15	9.0	3.6	14.3
	Northern Downs	≥ 15	15.6	8.0	23.3
	Northern Forest	< 15	17.5	10.3	24.7
	Northern Forest	≥ 15	16.7	10.3	23.1

The estimated population attributable fractions (PAF) of foetal and calf loss for risk factors retained in the full multivariable model are presented in Table 9-6. Estimates of the proportional reduction in the expected occurrence of foetal and calf loss for the study population should be interpreted with some caution as all interaction terms contained in the final model were omitted from the model the estimates of PAF are based on. Based on PAF estimates, top-order determinants for occurrence of foetal-calf loss within the study population were country-type, days temperature-humidity index >79 in calving month, hip height and nutritional indicators of wet season pasture. Also, body condition score at the pregnancy diagnosis muster, cow-age cohort, mustering efficiency and mustering within 2 months of expected calving were thought to be of similar importance.

Table 9-6. Estimated population attributable fraction of foetal-calf loss for risk factors contained in the full multivariable model.

Variable	PAF	95% Confidence Intervals	
		Lower	Upper
Country type	24.8%	-10.1%	48.6%
Temp-humidity index >79 in calving month	19.3%	12.3%	25.8%
Hip height	18.2%	-1.8%	34.3%
Average ratio of FP:ME during the wet season	16.2%	7.2%	24.3%
Lactating during previous reproductive cycle	12.8%	6.3%	18.9%
BCS at pregnancy diagnosis muster	12.6%	4.5%	19.9%
Cow age cohort	9.7%	4.3%	14.8%
Mustering efficiency	4.2%	1.7%	6.7%
Mustering within 2 months of expected calving	3.5%	2.1%	4.8%

Back fitting the final model demonstrated that inadequate dietary protein status (DMD:CP ratio of >8) during the dry season was associated with 4.2 percentage point higher loss compared to that for females with an adequate dry season dietary protein status.

The effects of several infectious diseases on foetal and calf loss were also tested by back fitting the final model (Table 9-7). In groups where there was a high prevalence of recent BVDV infection there was 9 percentage point higher foetal and calf loss than in groups with a low prevalence of recent infection. There was a non-significant trend for moderate-high prevalence of *Neospora caninum* infection to be associated with higher foetal and calf loss. In groups where the prevalence of samples positive for antibodies to *C. fetus* sp.*veneralis* was high, foetal and calf loss was 7 percentage points higher than in groups where the prevalence was low to moderate (p=0.02). There was no evidence that either *L. hardjo* or *L. pomona* infection was associated with foetal and calf loss. However, the observed seroprevalence and prevalence of recent infection with these serovars was generally very low. There was a trend for 6 percentage point higher loss in groups that had evidence of a moderate to high prevalence of recent infection with *L. pomona.* Further, back fitting of vaccination against leptospirosis to the final model showed a reduction in foetal and calf loss of 3.4 percentage points. Prevalence of antibody against either bovine ephemeral fever or *Coxiella burnetti* was not associated with foetal and calf loss.

A large number of other potential factors affecting foetal and calf loss were eliminated from the model, and remained with no effect when back fitted to the final model. Proportion of the paddock grazed within 2.5 km of water had no impact, though only a low overall proportion of paddocks were outside this level. Herd size did not significantly affect loss, but the trend was for management groups greater than 1,000 to have lower losses. Level of *Bos indicus* was not associated with foetal and calf loss. Back fitting month of calving showed a trend for highest loss when calving occurred in April-June, and lowest loss when calving in October-November (range of effect was 3.4 percentage points).

Table 9-7. Predicted means (%) for reproductive wastage associated with common infectious reproductive diseases (management group-level variables) that were back-fitted to the final model

Disease	Herd prevalence		Herd distribution (%)		% loss #
	Level	Criterion	2009	2011	(confidence interval)
BVD	Low	<10% AGID * 3+	42	64	11.5 ^{A} (6.5-16.4)
	Mod	10-30% AGID 3+	31	27	12.1 ^{A} (7.0-17.2)
	High	>30% AGID 3+	28	9	20.8 ^{B} (12.5-29.2)
C. fetus sp. veneralis	Low-Mod	<30% vaginal mucus Ab	98	89	12.9 ^{A} (8.4-17.4)
	High	≥30% vaginal mucus Ab	2	11	19.9 ^{B} (10.8-29.0)
Neospora caninum	Nil	0% sero-positive	19	24	12.6 (3.5-12.2)
	Low	0-20% sero-positive	55	53	12.0 (5.9-18.1)
	Mod-High	≥20% sero-positive	26	23	15.9 (7.0-24.9)

* Agar gel immuno-diffusion; #Means not sharing a common superscript are significantly different (P<0.05)

9.5 Discussion

If the 75th percentile is indicative of achievable foetal and calf loss in commercial beef herds, then this is <10% for Northern Forest herds, and <5% for beef herds in other country types. The large variation in foetal and calf loss across all of northern Australia clearly indicates there is an opportunity to reduce the loss by reducing the impact of the associated risk factors.

This study has demonstrated that environmental, nutritional and management risk factors have larger impact in northern Australia on reproductive wastage than disease and animal effects. Other than infectious diseases, predation and dehorning, calf death is likely to be the outcome of either the cow not providing enough milk, or the calf unable to suckle effectively (low vigour). When ambient temperatures are not high, non-suckling calves lose about 7% of their weight daily, which is equivalent to about 2.5 litres of milk daily (Fordyce *et al.* 2015). When calves lose 15% of their weight, they need intervention to survive. When ambient temperatures approach 40^{O}C, calves can lose this weight in one day, that is, neonates need at least 5 litres daily. Many cows may not be able to provide this if they have inadequate tissue reserves or are nutritionally-stressed. Fordyce *et al.* (1996) reported daily milk yield of first-lactation Brahman cross cows in mid-lactation of 3.6 kg. McBryde *et al.* (2013) found average milk yields of 3.3 kg/day from moderately-conditioned Brahman cows with a trend for milk yield to increase by 1 kg/day per unit increase in body condition score (5-point scale).

Other than *in utero* infections such as with BVDV, reasons for low calf vigour that may affect their ability to access milk and utilise nutrients are unclear. Riley *et al.* (2004) reported this trait to be heritable in Brahmans. Yates *et al.* (2012) in their review suggested that heat stress may also cause this outcome, in association with reduction in birth weight. Fordyce *et al.* (1993) previously showed that calf birth weight can be 25% lower in years with low pasture quality. Bunter *et al.* (2013) showed that birth weight less than one sd below the mean is associated with 8 percentage points higher calf mortality. Stress on cows that may be acute or chronic, eg, due to under-nutrition, may cause premature parturition, resulting in calves with low vigour and inadequate milk supply for the neonates. Dystocia is not commonly associated with calf loss in tropical cattle in northern Australia. However, Fordyce *et al.* (2009) reported large effects of dystocia in cows calving at two years of age when nutritional management did not adequately counter foeto-pelvic disproportion. The true extent of the effects of dystocia on calf viability and survival are unknown as this has been extremely difficult to study under extensive management conditions. Riley *et al.* (2004) has previously reported that dystocia in Brahman and Brahman cross cows reduces vigour of their calves at birth and increases mortality rates. The nutritional conditions associated with these outcomes could affect neonatal calf vigour and or milk production.

Environmental, nutritional and management risk factors that are highly likely to affect milk delivery identified in our study include low cow body condition, low phosphorus adequacy, low-nutrition environment, inadequate dry season pasture protein, high temperature-humidity index, mustering around calving and low mustering efficiency. This is further supported by at least two-thirds of calf mortalities occurring within a week of birth (Bunter *et al.* 2013). These risk factors have a combined effect of 30-40% on foetal calf loss, thus explaining high levels of reproductive wastage that have been reported from studies in the region. Although calf hydration appears to be a key element, the specific pathophysiology that results in calf death has not been explained in most cases; therefore, the exact manner of loss is not resolved. This reduces the ability to develop and apply remedial management.

An additional outcome from low and or delayed milk delivery to neonates is reduced volume and or quality of colostrum, thus increasing the risk of death due to neonatal diseases. Our finding that dry season protein adequacy is associated with lower foetal and calf loss is consistent with US studies demonstrating that cows experiencing marked dietary protein deficiency in the last trimester produced lower volumes of poorer quality colostrum and gave birth to calves that had reduced vigour (Bull *et al.* 1974; Stalker *et al.* 2006). The effect was dramatic in the Northern Forest, where much of the response may have been caused by variations in seasonal conditions, and that higher DMD:CP ratios could have been due to early rain, which dramatically improved both CP and DMD. This possibility is supported by such conditions having large effects on cow survival, in contrast to the much-lower nutritional effect of urea-based supplements. The analysis did not include foetal and calf losses due to cow mortality, but when nutritional conditions improve dramatically, there may be equally dramatic effects on cow and calf survival.

The reason for tall cows losing more calves is not clear. Irrespective of whether stature is a consequence of genetics or nutritional history, bigger cows may have proportionately-greater energy partitioning away from pregnancy and lactation than smaller cows. If so, this may be partially countered by improving the nutrition of tall cows during lactation, and or to select against large cows that may have lactation insufficiency.

A temperature-humidity index (THI) threshold of 79 for ≥15 days was based on an assessment of the univariable logistic regression models fitting counts of the days when the THI was >79 as the sole predictor of foetal and calf loss. Some of this loss may be related to direct heat load effects on the dam and/or calf. However, higher THI is also related to wet season rainfall, and calving into wet and boggy conditions may be as big a problem as heat load effects. The specific reason for the lack of effect in the Northern Forest is unclear, though environmental stress is always highest in this most northerly of the land types described.

Our research has shown that foetal and calf loss is at least lowly repeatable but not why. Teat and udder abnormalities and calf vigour at birth are potential contributors. Bunter and Johnston (2013) showed that reproductive wastage in tropical cattle in northern Australia is lowly heritable as previously reported for USA Brahmans (Riley *et al.* 2004). However, large teats and udders which are phenotypically and genetically correlated with calf loss are highly heritable (0.3; Bunter and Johnston (2013)). Both the repeatability and heritability elements of reproductive wastage may also be partially related to factors that affect calves' ability to acquire adequate milk for survival. Whether a cow should be retained for breeding depends on whether there is evidence for a cause of previous foetal and calf loss that is likely to be a recurring problem, and the relative expected future profitability of the cow as a function of her current weight, body condition, age, and expected time of next calving. If the causes of repeated foetal and calf loss could be better identified, they could be better targeted in selection, as long as research supports the hypothesis that the cause and the problem are both repeatable and heritable.

The likely role of aberrations in cow and calf behaviour contributing to loss is high and has previously been reported by Brown *et al.* (2003). Cow age and its effect on lactation competency and calf nursing experience are potential contributors to repeatable and heritable calf loss Burns *et al.* (2010). Overcoming these behavioural effects relies on a better understanding of how this occurs.

Wild dogs are prevalent across all north Australian beef production areas and losses were higher where beef producers perceived wild dog predation was a significant contributor. This study and that reported by Allen (2014) both found that typical measures to reduce wild dog populations in north Australian beef herds are more likely to be associated with an increase in calf predation than a decrease, which is counter-intuitive. Allen (2014) has suggested this is due to poison-baiting impacts on dog behaviour which causes them to target non-preferred species when they would usually prey native species. Predation control may be effective, but only when this is formulated using a sound understanding of the predators' ecology and likely impacts of control measures on their behaviour.

The high prevalence of recent Bovine Viral Diarrhoea Virus (BVDV) infection in cows sampled in early-mid pregnancy being associated with higher foetal and calf loss than in herds with a low prevalence of recent infection is consistent with recent reports (Kirkland *et al.* 2012; Morton *et al.* 2013). Also consistent is the low proportion of cattle herds having recent BVDV infection. A majority of the cattle in these herds would have been pregnant, and hence evidence of recent infection with BVDV would indicate an increased risk of in-utero infection with BVDV. Kirkland *et al.* (2012) and Morton *et al.* (2013) both reported that half the herds they studied had 0-30% sero-positive animals, compared to 15-31% in our study, indicating high susceptibility to the virus.

The lack of effect of Neopsorosis on foetal and calf loss is consistent with the findings of the study conducted by Fordyce *et al.* (2013b) in the same broad region, but sharply contrasts with studies of the impact of *N. caninum* infection of dairy cattle on the Atherton tableland in northern Australia (Landmann *et al.* 2011) and elsewhere in the world where cattle are usually more intensively managed. The reason for this difference is not apparent, but one could speculate that because wild dogs have been shown to be a carrier of this organism (King *et al.* 2012) and are common across the beef breeding regions of northern Australia, that exposure of young heifers to pastures contaminated with faeces from wild dogs may result in them becoming immune to infection (Williams *et al.* 2009).

Generally camplyobacterosis is associated with conception failure and delayed conception, although an abortion rate of 5 to 10% (usually between the 5th to 7th months of gestation) has been reported (Clark 1971). Because camplyobacterosis is usually associated with embryo loss prior to foetal ageing, it was surprising to find the large impact on foetal and calf loss. It is possible that some of this effect was because a high prevalence of *C. fetus* sp. *veneralis* infection is associated with a higher prevalence of other diseases causing loss that were not tested, eg, venereal infection with *Tritrichomonas fetus*.

Under extensive management, our findings support routine vaccination against leptospirosis in situations where a high prevalence of *L. pomona* is known or likely (McGowan 2003). Outside these situations, vaccination may be reduce the chance of zoonoses, but is unlikely to achieve cost-effective reduction in reproductive wastage.

While there are several modelling options to analyse binary data with hierarchical structure, the method with which models computationally handle clustering or grouping of data can be generally categorised as either having a "population-averaged" or "subject-specific" approach.

Random-effect logistic regression models were employed in the present study, generating subject-specific estimates of regression coefficients (odds ratios), and predicted probabilities. Subject-specific models explicitly manage dependencies by incorporating a random effect for each subject in the model (random intercept). Because the estimated effects are adjusted for unmeasured individual differences, they are termed "subject-specific" effects. Odds-ratios estimated from the subject-specific model should be interpreted as representing the change for a single individual or for those individuals with the same random effect estimate.

The population-averaged model describes changes in the population mean given changes in covariates, and does not have a subject-specific focus. Odds-ratios estimated from the population-averaged model should be interpreted as representing the change for an average subject. Population-averaged effect estimates, although not reported, were generated and were found to be numerically very similar to those generated using subject-specific estimators. For the more informed reader equations exist to convert subject-specific effect estimates to population averaged such as those reported by Dohoo *et al.* (2009).

Population attributable fraction estimates are useful for providing a measure of the relative importance of risk factors, as both the strength of the risk factors' association with the non-pregnancy and the prevalence of the risk factor within the population is computationally included in its estimation. It is acknowledged that a shortcoming of the PAF estimates reported here is that interaction terms contained in the final model were omitted from the model used to estimate PAF for each risk factor due to computational limitations. Therefore, presented PAF results should be interpreted with appropriate caution and emphasis is suggested to be placed towards the likely relative importance of different risk factors rather than the PAF estimate.

The major conclusion from this research is that a wide range of risk factors can have large and additive effects on foetal and calf loss. In northern Australia, the combined effects of environmental, nutritional and management risk factors are usually much greater and more consistent than that due to either endemic infectious diseases or animal factors. It is suggested that remedial action for the effect of non-infectious risk factors should target milk delivery to neonatal calves.

9.6 Contributions by others to the chapter

Mr McCosker was responsible for the management of the data across all country types and capturing the data within the country type of Northern Forrest. Mr McCosker was responsible for the cleaning and validation of data, which was overseen by Professor O'Rourke, and conducted preliminary univariate and multivariate analyses. Mr McCosker provided support to Dr Barnes, who completed the final multivariate analyses which was overseen by Professor Perkins. Estimation of the population attributable fractions was completed by Mr McCosker who also contributed significantly to the interpretation of the data. The writing of this chapter occurred in preparation for submission of a manuscript which was drafted by Mr McCosker. The finalisation of the 'in preparation' manuscript was completed by Dr Geoffry Fordyce. Professor McGowan, Dr Fordyce, and Professor O'Rourke have also had a substantial intellectual contribution to the interpretation of the data.

9.7 Additional Material

9.7.1 Univariable screening

Descriptive statistics and herd-adjusted odds ratios and P values for 30 exposure variables that were eligible to enter the final logistic regression model as potential risk factors for risk of non-pregnancy in beef breeding females are presented in Table 9-8, Table 9-9 and Table 9-10.

Information relating to an additional eight candidate risk factors were not considered for inclusion in the multivariable modelling process due to having ≥40% incomplete records. These were:

- Body condition score change between pregnancy diagnosis and branding or weaning muster (Lost / Maintained / Gained)
- Successfully raised confirmed pregnancy in previous reproductive cycle (Yes / No)

The following candidate risk factors were not considered in the multivariate model building process as on candidate risk factor screening were found to be not statistically significant at ≤0.2.

- Bull: Female ratio (<3:100/ ≥3:100)
- Body condition score at the pregnancy diagnosis muster (1.0-2/ 2.5/ 3/ 3.5/ 4.0-5)
- Timing of wet season onset (Early / Normal / Late)
- Average DMD:CP during the dry season (≥8:1 / <8:1)
- Provision of supplemental nitrogen (No / Yes)
- Provision of supplemental phosphorus (No / Yes)
- Average wet season dietary crude protein (<7% / ≥7%)
- Average wet season dry matter digestibilty (<55% / ≥55%)
- Predominant turnoff animal for enterprise (Bullocks / Feeders / Weaners)

Table 9-8. Results of herd-adjusted logistic regression screening candidate herd management risk factors and probability of foetal and calf loss between confirmed pregnancy and weaning in surviving cows, with odds ratio (OR) 95% confidence interval (95% CI) of OR, and P value. Results restricted to only those risk factors with unconditional P values ≤0.2.

Variable	Raw observations Foetal or Calf Loss (n)	Survived (n)	OR	95% CI of OR Lower	Upper	p-value
Genotype						P=0.001
≥75% *Bos indicus*	10,153	36,285	Ref			
<75% *Bos indicus*	4,730	11,155	1.89	1.30	2.75	
Average size of management group at pregnancy diagnosis						P=0.01
<150	312	4235	Ref			
≥150 to <400	2557	20274	1.83	1.14	2.93	
≥400	2474	16213	2.68	1.50	4.81	
Bull selection policy						P=0.01
Nil best practice	2557	16645	Ref			
Some best practice	631	7275	0.44	0.26	0.75	
Most best practice	1775	15098	0.68	0.44	1.05	
Annual bull management policy						P=0.05
Nil best practice	2391	15256	Ref			
Some best practice	905	8596	0.55	0.34	0.90	
Most best practice	1667	15166	0.58	0.34	0.99	
Culling age of breeding females						P=0.17
8 years	203	2666	Ref			
9 years	7	220	0.38	0.06	2.58	
10 years	3658	26149	1.64	0.76	3.58	
11 years	245	1540	2.01	0.71	5.68	
12 years	144	1857	0.86	0.34	2.22	
Not practiced	583	4273	1.61	0.65	4.00	
Mating management						P<0.0001
≤3m	777	11457	Ref			
>3 to ≤7m	1626	13428	1.80	1.17	2.76	
>7m without seg	1527	7072	3.18	2.03	4.99	
>7m with seg	1315	8438	1.58	0.65	3.84	
Impact of wild dogs						P=0.01
Active	3900	25148	Ref			
Little	744	7618	0.52	0.31	0.87	
Not Present	382	4272	0.45	0.25	0.83	
Mustered within a month of calving						P=0.001
Not mustered	4579	35054	Ref			
Mustered	743	5473	1.19	1.09	1.30	
Mustering efficiency						P=0.01
>90%	4,925	38,663	Ref			
<90%	382	1,894	2.07	1.18	3.62	
Method of mustering						P=0.002
Aerial	3643	23762	Ref			
Ground	1292	14568	0.51	0.35	0.74	
Trapping	278	1940	0.80	0.35	1.83	
Botulinium property vaccination policy						P=0.01
Not vaccinated	1436	14034	Ref			
Vaccinated	3848	25376	1.63	1.12	2.38	
Leptospiros property vaccination policy						P=0.001
Vaccinated	4208	27141	Ref			
Not vaccinated	1076	12269	0.49	0.33	0.73	
BEF property vaccination policy						P=0.001
Bulls	674	8644	Ref			
Herd	78	1112	1.07	0.23	4.98	
Nil	4532	29654	2.20	1.45	3.34	

Table 9-9. Results of herd-adjusted logistic regression screening candidate animal attributes and risk factors and probability of foetal and calf loss between confirmed pregnancy and weaning in surviving cows, with odds ratio (OR) 95% confidence interval (95% CI) of OR, and P value. Results restricted to only those risk factors with unconditional P values ≤0.2.

Variable	Raw observations: Foetal or Calf Loss (n)	Raw observations: Survived (n)	OR	95% CI of OR: Lower	95% CI of OR: Upper	p-value
Cow-age class cohort						P<0.001
1st pregnancy	1156	6918				
2nd pregnancy	406	3752	0.70	0.61	0.80	
Mature	2923	23752	0.62	0.57	0.68	
>9 years	858	6300	0.66	0.59	0.74	
Estimated period of calving expressed as predicted window when the cow calved						P=0.001
Jul-Sep	693	5453	0.97	0.87	1.09	
Oct-Nov	1700	13506	1.00	0.93	1.09	
Dec-Jan	1836	14211	Ref			
Feb-Mar	777	4879	1.14	1.04	1.26	
Apr-Jun	327	2481	0.85	0.75	0.97	
Pregnant	10	191	0.60	0.31	1.18	
Body condition score at the branding or weaning muster						P=0.001
1.0-2	216	2406				
2.5	420	3833	1.20	1.00	1.45	
3	1015	8366	1.26	1.06	1.50	
3.5	836	5655	1.41	1.18	1.68	
4.0-5	592	4650	1.44	1.20	1.72	
Lactated previous reproductive cycle						P<0.001
Not lactating	2339	13532	Ref			
Lactating	2279	22378	0.70	0.65	0.75	
Hip height						P=0.01
<=125	129	1225				
125-140	2322	18349	1.12	0.91	1.38	
>140	884	6501	1.28	1.02	1.60	

Table 9-10. Results of herd-adjusted logistic regression screening candidate nutritional and environmental risk factors and probability of foetal and calf loss between confirmed pregnancy and weaning in surviving cows, with odds ratio (OR) 95% confidence interval (95% CI) of OR, and P value. Results restricted to only those risk factors with unconditional P values ≤0.2.

Variable	Raw observations		OR	95% CI of OR		p-value
	Foetal or Calf Loss (n)	Survived (n)		Lower	Upper	
Country type						P<0.001
Southern Forest	575	7,135				
Central Forest	640	7,509	1.09	0.66	1.81	
Northern Downs	1,874	14,411	1.27	0.75	2.15	
Northern Forest	2,254	11,667	2.80	1.82	4.33	
Year observed						P<0.001
2008	338	2,222				
2009	2,883	20,205	0.86	0.74	0.99	
2010	2,122	18,295	0.69	0.60	0.80	
Wet season duration						P<0.001
Early	563	4596				
Normal	3738	25726	1.43	1.28	1.60	
Late	914	9501	1.95	1.64	2.32	
Average THI during month of calving						P<0.001
<79	1338	14026	Ref			
≥79	3995	26504	1.34	1.23	1.46	
No of days THI > 72 during month of calving						P<0.001
<25days	655	7505				
≥25days	4678	33025	1.33	1.18	1.50	
No of days THI > 79 during month of calving						P<0.001
<15days	1395	13848				
≥15days	3938	26682	1.27	1.17	1.39	
No of days maximum temperature >32°C during month of calving						P<0.001
<15days	2082	19213				
≥15days	3251	21317	1.24	1.15	1.35	
Average dry season dietary crude protein						P<0.001
<7%	3587	29952				
≥7%	1091	8069	1.48	1.32	1.65	
Average dry season dry matter digestibility						P<0.001
<55%	3592	30081				
≥55%	1086	7940	1.30	1.17	1.46	
Average DMD:CP during the dry season						P<0.001
<8:1	1547	12676	0.97	0.83	1.13	
≥8:1	3131	25345	Ref			
Average DMD:CP during the wet season						P<0.0001
<8:1	3020	24602	1.25	1.14	1.38	
≥8:1	1343	9836	Ref			
Average FP:ME during the wet season						P<0.0001
≥500 mgP : 1 MJ ME	952	11988	0.71	0.62	0.80	
<500 mgP : 1 MJ ME	3411	22450	Ref			

Abbreviations: THI, temperature humidity index; FP:ME, Ratio of faecal phosphorus to metabolisable energy; DMD:CP, ratio of dry matter digestibility to dietary crude protein

9.7.2 Model performance

Distributions of observed and expected frequencies differed significantly (P<0.001) when expected frequencies were based on the fixed part of the final model, suggesting that the fixed part of the model was poorly calibrated. The fixed part of final multivariable model fitted the data only partially well with more than expected cases of confirmed pregnancy to weaning loss moderate to lower probabilities (Table 9-11).

Table 9-11. Observed (Obs) and expected (Exp) frequencies by decile of risk using estimated probabilities from the fixed part of the final model of non-pregnancy.

		Confirmed pregnancy to weaning loss				
		Loss		Survived		
Decile	Probability	Obs	Exp	Obs	Exp	Total
1	0.039	129	93	2,244	2,280	2,373
2	0.050	119	116	2,210	2,213	2,329
3	0.057	130	128	2,123	2,125	2,253
4	0.071	181	165	2,136	2,152	2,317
5	0.087	228	203	2,089	2,114	2,317
6	0.102	271	240	2,080	2,111	2,351
7	0.115	342	262	1,937	2,017	2,279
8	0.130	362	323	2,129	2,168	2,491
9	0.147	392	356	2,025	2,061	2,417
10	0.215	399	439	1,640	1,600	2,039

Only 3.7% of standardized residuals were either >3 or <-3. This is greater than the expected 1% but not a sufficiently high percentage to be a cause for concern. A visual inspection of the scatterplots of the delta-chi squared statistic against predicted probability and Pregibon's dbeta against predicted probability revealed several extreme covariate patterns with values far from the majority. The lack of fit was considered likely to have been influenced by the large sample size, as previously described (Paul *et al.* 2013). Rerunning the model without these covariate patterns (dropping 1,816 observations) resulted in some proportionally large changes in the coefficients. In many cases the starting values of the coefficients were numerically small, thus a small absolute change resulted in a large proportional change and the majority of these altered coefficients were not significant. There were no changes in the significance of coefficients or the direction of effect, thus the only consequence of dropping these observations from the model was an alteration in the magnitude of the effect of some variables. As there are no grounds for dropping these observations from the dataset the original random effects model with 23,166 observations was retained.

The final model had an acceptable ability to discriminate between those cows that were positive for non-pregnancy to those that were not, with 60.8% correct predictions. Using a probability cut point of 0.107, determined by inspection of a graph of the sensitivity and specificity versus the probability cut points (Figure 9-3), classification statistics were calculated and are presented inTable 9-12. Sensitivity was high (>0.90) at very low probability cut points (<0.05) while, specificity was high (>0.90) at probability cut points >0.2 (Figure 9-3). The area under the receiver operating characteristic curve was estimated as 0.64 (95% CI, 0.63-0.65) (Figure 9-4).

Table 9-12. Classification for the final model based on the probability cutpoint 0.107.

Observed FCL	Classified (predicted) status		Total
	pr(FCL)<0.107	pr(non-preg)≥0.107	
0	12,525	8,088	20,613
1	1,003	1,550	2,553
Total	13,528	9,638	23,166

Sensitivity	6.69%
Specificity	34.91%
Positive Predictive value	60.71%
Negative Predictive value	60.76%
Percent correct predictions	60.76%

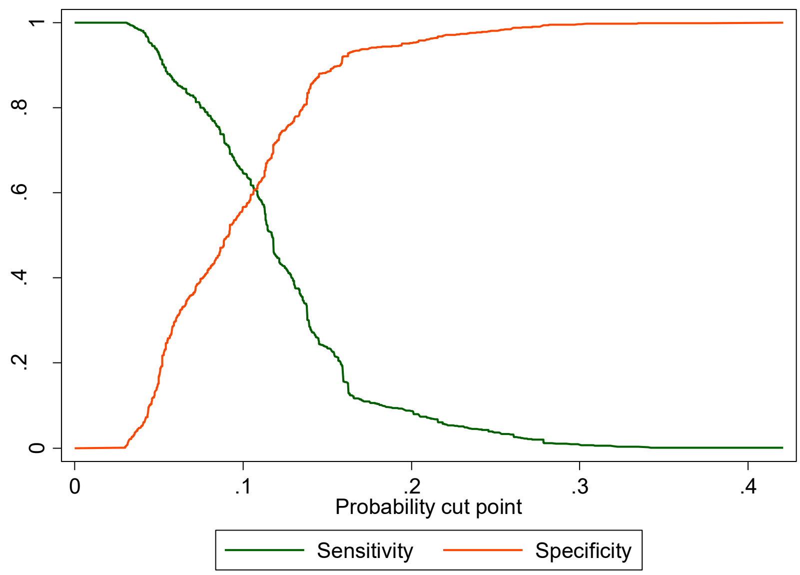

Figure 9-3. Sensitivity and specificity of the final model.

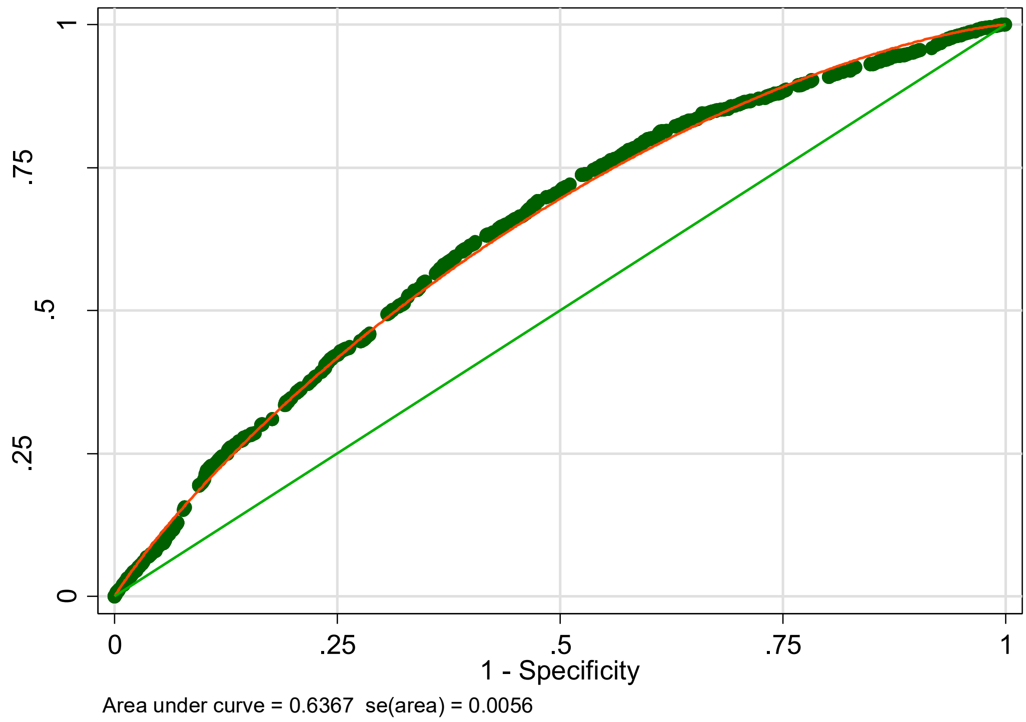

Figure 9-4. Area under the receiver operating characteristic curve using only the fixed part of the final model.

Chapter 10 General Discussion and Conclusions

10.1 Purpose of this chapter

The purpose of this chapter is to discuss the general findings arising from this research thesis and how they extend the current knowledge of north Australian commercial beef production systems. This thesis has used investigatory techniques to determine the major risk factors associated with reproductive performance, described their prevalence within northern beef cattle herds (Chapter 6), and quantified their impact on measures of reproductive performance (Chapter 7 , Chapter 8 and Chapter 9). In addition, this thesis has monitored and described the reproductive performance of commercial beef herds and defined achievable performance levels using both novel and established measures of reproductive performance in the current economic framework for the major beef producing country types of Northern Australia (Chapter 5). Based on these findings, recommendations for herd managers and industry research, development and extension stakeholders are made.

10.2 General Discussion and Conclusions

10.2.1 Measured reproductive performance in Northern Australia

A unique feature of this research thesis has been the simultaneous monitoring of reproductive performance for cohorts of breeding females differing in cow-age class under commercial conditions and across the major beef producing areas of north Australian and summarising levels of herd performance for novel and established measures of reproductive efficiency. Other than surveys, there are no or limited data of either mortality or reproductive rates at a regional or national level in Australia and highlights the importance of such large scale observational studies. These estimates of achievable performance however, should be interpreted with appropriate caution as the specific focus of the studies completed in this thesis were primarily focused on outputs and a full business analysis was not conducted. Therefore, it is not known if the achievable levels of performance for the measures of reproductive efficiency reflect the maximum economic value. However the study, for which this thesis relates, describes for the first time median ('typical') and lower boundary of the top 25% ('achievable') levels of observed performance attained by commercial beef producers within four broad country types of northern Australia using a standardised approach. Whilst inferences relating to their economic value would require estimation, the use of comparative business programs and benchmarks within agricultural industries are used by advisors and government agencies with the aim to enhance the viability and competiveness of farmers (Ronan and Cleary 2000). Furthermore, these values are borne from the simultaneous monitoring of herds across 3-4 years that were operating under a commercial economic framework and therefore, are likely to take into account levels of performance that were achieved randomly or due to over investment and are considered to provide useful estimates for RD&E agencies to guide future research and discussions with herd managers/owners on reproductive management and performance.

This study observed large variation in reproductive performance for commercial herds for all measures. There was 20-30 percentage point variation in reproductive rates and 5-15 percentage point variation in foetal/calf loss for half the herds in all regions. The mid-spread of performance within cow-age class was reasonably consistent across all country types except in the Northern Forest where percent pregnant was considerably lower, and reproductive wastage, cow mortalities and retained non-pregnant cows to be rebred were considerably higher than in other regions.

With the exception of Northern Forest, previous attempts to define benchmark levels of reproductive performance are generally applicable for the monitored performance in this study. For mature and aged cows within the Northern Forest, the level of performance attained by the most favoured 25% of herds was approximately 75% for annual pregnancy percentage and 65% of surviving cows contributing a weaner. In contrast, Burns *et al.* (2010) suggested a reasonable target for weaning rate for beef herds within northern Australia was 75-80 weaners per 100 cows exposed, while Holroyd (1987) defined an ‘acceptable loss’ of foetal and calf loss was in the order of 12%. Therefore by deduction, an overall annual pregnancy percentage of 85-90% could be proposed as an appropriate level for north Australian beef herds. Therefore, the measured performance in this study is potentially much lower for the Northern Forest than that previously considered achievable by many herd managers, advisors and government agencies and highlights the value of demonstrating what is achievable under commercial, rather than controlled-research, management.

The novel measure of reproductive efficiency P4M, was described for the first time for north Australian beef cattle herds in this research thesis. P4M is consistent with the previously reported average interval from calving for which lactating cows conceived of 3.9 months within a research herd in the Victoria River District of the Northern Territory (O'Rourke 1994) and reflects those cows that are likely to contribute a weaned calf in consecutive years. This measure is comparable to the 100-day in-calf rate reproductive performance measure established within the Australian dairy industry (Morton 2004). However for commercial enterprises within northern Australia, 100 day in-calf rate is not a suitable measure due to the measurement errors associated with determining foetal age via rectal palpation and between animal variability for gestation length (Casas *et al.* 2011).

The median level of P4M for first-lactation cows was consistently approximately 60% of that achieved for mature and aged cow cohorts across regions and is consistent with previous reports (Entwistle 1983; Schatz and Hearnden 2008; Burns *et al.* 2010). In exception to other regions second-lactation cow cohorts within the Northern Forest had the lowest median P4M values compared to other cow-age classes suggesting that the environmental stressors within the region are too great to support females contributing three calves in three mating opportunities unless external inputs are provided.

The opportunity to increase herd profitability appears to be the greatest in the Northern Forest as the median level of monitored performance was ~50% of surviving cows contributing a weaner with others previously suggesting that when male sale age exceeds 3 years, increasing weaning rates above 75% often does not result in improvements to herd profitability (Entwistle 1983). In addition, based on median levels of performance, cow mortality rates were ~4 percentage points higher within the Northern Forest than other regions, which is widely accepted to negatively impact profitability and potential viability of enterprises of northern Australia (O'Rourke 1994; McCosker *et al.* 2010b). While these findings suggest that improvements in reproductive performance within the Northern Forest could clearly be made, the whole of business impact of making interventions is required as their associated costs may outweigh the returns and therefore, low-cost strategies to improve herd productivity need to be explored further.

10.2.2 Major sources of variation in reproductive performance of beef breeding herds in Northern Australia

This study is thought to be the first population-based epidemiologic study to determine the factors associated with reproductive performance in commercial beef herds of Australia. Historically, a number of studies have been conducted using various approaches to evaluate the impact of known risk factors on reproductive performance (Hasker 2000). In the studies contained in this thesis, the associations between some 83 candidate risk factors and the occurrence of heifers and cows either which become pregnant in an annual production year, P4M or risk of pregnant females failing to contribute a live calf at muster were assessed under commercial conditions and highlights the importance of conducting large observational studies in the target population for research.

The statistical models developed in the studies for which this thesis is concerned may be described as explanatory rather than predictive. Explanatory research aims to identify risk factors that are causally related to an outcome while predictive research aims to find the combination of factors that best predicts a current diagnosis or future event (Sainani 2014). Explanatory models are generally used to improve our understanding of the factors that can influence an outcome, such as pregnancy percentage in beef cows. Thus, the associations in explanatory models have to be based on biologically sound possibilities so they can be used to guide future investment and resources to develop interventions.

Population-based research methods allow the determination of the major risk factors associated with measures of reproductive performance and using prevalence information estimate the theoretical reduction in reproductive performance that could be prevented if the effects associated with risk factors of interest were removed from the population (Rockhill *et al.* 1998). Such knowledge is of direct interest to industry stakeholders to guide research, development and extension investment decisions and to allow managers to implement targeted management decisions to mitigate the influence of prominent and important risk factors. Due to no known similar studies being conducted within northern Australia, discussion of differences in findings cannot be explored. The practical usefulness of determining risk factors of greatest population effect is that intervention can be prioritised towards those risk factors.

It is acknowledged however that a shortcoming of the PAF estimates reported within this thesis is that interaction terms which were contained in final models were omitted from models used to estimate PAF due to computational limitations. In an attempt to explore the effect of omitting interaction terms, PAF estimates from models including dummy coded interaction terms were explored. Moderate changes to the estimated proportional reduction in percent cows that failed to become pregnant within 4 months were evident although, the ranking of risk factors were overall considered comparable. Therefore, presented PAF results should be interpreted with appropriate caution and emphasis is suggested to be placed towards the likely relative importance of different risk factors rather than the PAF estimate. These analyses reaffirmed that reproductive history (lactation and time of calving) and indicators of body reserves at critical time points (weaning or pregnancy diagnosis) are top-order determinants for all reproductive outcomes. When approximately the temperature-humidity index exceeded 79 for at least two weeks during the month of calving and is of phosphorus deficiency were ranked as highly important risk factors with respect to foetal/calf loss and are under the potential control of herd managers.

Multilevel modelling also allows the determination of sources of variation between levels of organisation. In this study, it was determined that 49.7, 28.1% and 33.9% of the property level variance for the outcomes P4M, non-pregnancy and foetal/calf loss, respectively was explained from the final models. This suggests that many important factors impacting on the reproductive performance of beef cows in north Australia were accounted for in the models. However, improvement to the modelling of probability of cows successfully achieving these outcomes is likely to result from further refinement of the factors considered in the final models or addition of further variables. This highlights the potential role for individual animal recording systems to monitor and manage individual animal performance and risk factors to facilitate ongoing future improvement of beef herd productivity within northern Australia.

There was significant evidence for clustering at the property (herd) level as by adding the fixed effects to the P4M, non-pregnancy and foetal/calf loss models, respectively explained 49.7%, 28.1% and 33.9% of the variance at the property level that had been estimated using an intercept only model. However, the residual intra-class correlation estimates from the final models were 0.23, 0.18 and 0.13 for P4M, non-pregnancy and foetal/calf loss, respectively suggesting that the proportion of the overall residual variation that is attributable to property level effects not explained by the fitted variables, is still relatively large. Therefore, improvement to the modelling of these reproductive outcomes could result from further refinement of the variables considered in the final model or addition of further variables.

10.2.3 Assessment of risk factors

As aforementioned, the statistical approach in the studies with which this thesis is concerned has been to develop parsimonious explanatory models to help identify and understand the major determinants for reproductive performance, and to inform the development of management strategies to improve the performance of cows within commercial beef herds of northern Australia. The associations of approximately 83 individual candidate risk factors, which can be classed as relating to nutrition, management, environment, genotype/phenotype or infectious disease, were considered for each explanatory model.

It was hypothesised that the major risk factors determining the probability of lactating cows becoming pregnant within four months of calving are similar to those determining the probability of foetal/calf loss between confirmed pregnancy and weaning. In support of this hypothesis, results of studies for which this thesis relates demonstrated that parameters describing previous and current nutritional characteristics and physiological maturity of females (country type, cow-age class, body condition score and risk of phosphorus deficiency) were key determinants of both probability of cows becoming pregnant within four months of calving and pregnant cows successfully contributing a calf at muster. However, in addition to these risk factors, associations of further risk factors (mustering and heat stress around the time of calving), more isolated in their effect on reproductive performance, were also identified as important.

The following section aims to discuss the risk factors retained in the final models or there was interest in estimating its effects using the final model. The factors that were not retained in the final model were dropped from the model due to other variables explaining greater proportions of variance or their associated effects being represented by other variables retained in the model.

While there are several modelling options to analyse binary data with hierarchical structure, the method with which models computationally handle clustering or grouping of data can be generally categorised as either having a "population-averaged" or "subject-specific" approach.

Random-effect logistic regression models were employed in the present study, generating subject-specific estimates of regression coefficients (odds ratios), and predicted probabilities. Subject-specific models explicitly manage dependencies by incorporating a random effect for each subject in the model (random intercept). Because the estimated effects are adjusted for unmeasured individual differences, they are termed "subject-specific" effects. Odds-ratios estimated from the subject-specific model should be interpreted as representing the change for a single individual or for those individuals with the same random effect estimate.

The population-averaged model describes changes in the population mean given changes in covariates, and does not have a subject-specific focus. Odds-ratios estimated from the population-averaged model should be interpreted as representing the change for an average subject. Population-averaged effect estimates, although not reported, were generated and were found to be numerically very similar to those generated using subject-specific estimators. For the more informed reader equations exist to convert subject-specific effect estimates to population averaged such as those reported by Dohoo *et al.* (2009).

10.2.3.1 Assessment of nutritional effects

The associated effects of nutrition on outcomes of reproductive performance were represented by several variables in each of the final models and included season (year), country type, body condition score and its change, dry season dry matter digestibility, indicators of protein adequacy during both wet and dry seasons, risk of wet season phosphorus deficiency, and month of calving. Not all of these risk factors were identified as major determinants for each reproductive outcome. However, it further validates the known impact nutrition has on the efficiency with which cows achieve pregnancy after calving (Samadi *et al.* 2013) and its association with foetal/calf losses between confirmed pregnancy and weaning are consistent with previous findings relating to milk yield (Roche *et al.* 2009).

Prolonged interval between calving and the resumption of cycling has been identified as the single biggest factor affecting the reproductive performance of beef breeding cattle within northern Australia (Entwistle 1983). Adequate BCS prior to calving and high-quality nutritional during early lactation and around the time of calving are known to result in reduced intervals from calving to the resumption of cycling (Wettemann *et al.* 2003). These observations are explained by a vast amount of research describing the influence of nutrition on the process of folliculogenesis, which occurs across a 5-month timeframe for individual ova and at all stages is sensitive to nutritional regulators (Scaramuzzi *et al.* 2011).

It is postulated that BCS measured at the pregnancy diagnosis muster was identified as the strongest predictor of P4M, and not at the earlier muster where lactation status was assessed, and branding or weaning occurred, for each of the following reasons: is likely to be better representation of the BCS of cows at calving than that measured approximately 4-5 months prior (when potentially lactating and before the dry season); more complete information is available at the pregnancy diagnosis muster due to a greater emphasis is placed on cow attendance at pregnancy diagnosis and increased efficiency of mustering due to less surface water within paddocks; and reduced error in the assessment of BCS at pregnancy diagnosis as cattle are restrained for pregnancy diagnosis. This finding was consistent with those reported by Waldner and García Guerra (2013).

With the exception of Northern Forest, there was approximately a 10-15 percentage point improvement in P4M for each unit increase in BCS and is consistent with other findings reported in the literature (Rae *et al.* 1993; Dixon 1998). There was a trend for greater improvement in reproductive performance at lower BCS values. However within the Northern Forest, the expected occurrence of P4M for cows in BCS 3.0, 3.5, and 4 to 5 were not significantly different. Whilst this finding within the Northern Forest cannot be explained in full, it is not dissimilar to the finding were the odds of non-pregnancy at BCS 5 (1-9 scale) were statistically similar to those at BCS 7, 8 & 9 when BCS at pregnancy diagnosis was contained in multivariable models for the outcome non-pregnancy (Waldner and García Guerra 2013). The proportion of lactating cows with ≤2.0 BCS at the branding/weaning muster was approximately three times that of other regions and suggests that the environmental conditions within the Northern Forest are unlikely to meet the nutritional demands of early lactation resulting in a state of negative energy balance. Cows in higher body condition at pregnancy diagnosis are likely to have higher maintenance energy requirement due to increased liveweight and milk yields, resulting in the excessive mobilisation of body reserves. Cows that maintained or lost condition between pregnancy diagnosis and branding/weaning were estimated to have a 9.2 percentage point lower expected occurrence of P4M. Rather than discounting the importance of body condition in the Northern Forest, this research emphasises that management practices that maintain body condition are more important than in other areas, as excessive weight loss may lead to both cow and calf mortality (Fordyce *et al.* 1990).

Providing there are no mineral deficiencies, the fundamental nutritional drivers to support lactation and maintain body condition are the intake of digestible dry matter and crude protein. Which potentially explains the findings that the percentage of lactating cows that achieved P4M was 7.5% lower in cows grazing pasture with an average wet season DMD:CP ratio of >8:1 and is consistent with other research findings (Samadi *et al.* 2013). Therefore management practices that support the alignment of lactation and pasture of adequate quality and quantity are critical, particularly within the Northern Forest. Thus, managing the majority of cows to calve just prior to or early in the wet season and subsequently timing weaning to occur near the end of the growing season will ensure most cows are in good condition prior to their next calving. Alternatively for a continuously mated herd, the use of foetal ageing to segregate heifers and cows according to 3-month calving windows enables more precise timing of weaning (Braithwaite and deWitte 1999a)

The associated effects of time of calving on reproductive performance are well established and recognised (O'Rourke 1994) and was identified as a major determinant for the outcomes of P4M and non-pregnancy but not for foetal/calf loss. However, was not contained in the final foetal/calf loss model. The associated effects of time of calving on pregnancy are thought to be explained by the available nutrition to support lactation and the resumption of cycling after calving. The expected occurrence of non-pregnancy generally increased as categories of calving period advanced and is similar to findings reported by O'Rourke (1994) and was dependant on cow-age class and BCS measured at the branding/weaning muster. Cows that calve early in the calving period have longer to return to ovarian cyclicity and achieve pregnancy by the end of the mating period.

Percentage P4M was lowest within the period July to September and highest within December to January, with the odds of P4M nine times that estimated for P4M during July to September. Cows lactating during the dry season have been associated with 10-15kg loss of liveweight per month (Dixon 1998) and demonstrate prolonged periods of lactation anoestrus (Cobiac 2006). This finding suggests that herd managers should consider mating and weaning management of heifers and cows to synchronise lactation with above-maintenance nutrition. However, a whole of business analysis should be completed during this process as factors such as liveweight at weaning and market incentives may be driving some calving windows currently preferred by herd managers.

The average ratio of faecal phosphorus to metabolisable energy threshold value of 500 mg P/kg ME was used to describe the risk of phosphorus deficiency adversely impacting on cow reproductive performance within the studies for which this thesis is concerned after it was determined to be a stronger predictor of P4M, as inferred by Akaike's and Bayesian Information Criteria (Dziak *et al.* 2012), than the threshold values of 420 or 450 mg P/kg ME. A threshold value of 420 mg P/kg ME has been recommended by Jackson *et al.* (2012) for a 400 kg lactating cow (5 L milk/day) maintaining weight and grazing pasture of 54% DMD. Why the threshold value of 500 mg P/kg ME was a stronger predictor than 420 mg P/kg ME for P4M cannot be explained; however, a 400 kg average liveweight for cows during early lactation is likely to be only relevant to the Northern Forest with heavier average liveweight of cows likely within other regions. In contrast, the average DMD of pastures within these regions during the wet season were observed to be above 54% DMD (Chapter 4) and likely to support above maintenance performance of cows from increased energy and protein intake thus, reducing the FP:ME threshold value for adequacy (Jackson *et al.* 2012). Interpretation of these values is further complicated by availability of supplementary P during sampling times. However, using the threshold value of 500 mg P/kg ME, the average wet season FP:ME ratio was identified as a major determinant for all of the reproduction outcomes of interest in this study, further validating that phosphorus adequacy is a major determinant of reproductive performance of cows within northern Australia and FP:ME ratio appears to enable an assessment of the relative risk of phosphorus deficiency to be discerned.

The association between risk of phosphorus deficiency adversely impacting on cow reproductive performance and P4M was dependent on cow-age class. The estimated percentage P4M for first-lactation, mature and aged cows categorised as being of low risk of phosphorus deficiency (<500 mg P/kg ME) was 20.3, 2.5 and 8.3 percentage points, respectively higher and statistically significant than those cows categorised as being of elevated risk of phosphorus deficiency (≥500 mg P/kg ME). The difference in P4M for second-lactation cows was not statistically significant. The majority of skeletal and muscle growth for cows occurs within 4.5 years from birth (Fordyce *et al.* 2013a) and therefore, first-lactation cows are likely to have reduced ability to mobilise tissue reserves to meet the additional nutritional requirements associated with lactation. These findings further strengthen the recommendation by Miller *et al.* (1997) that "Growing heifers and first-calf cows should be targeted for aggressive and comprehensive phosphorus management".

The adverse association between risk of phosphorus deficiency and cow reproductive performance and non-pregnancy was dependent on country type and average wet-season DMD:CP ratio. For cows with average wet season DMD:CP ratios >8:1 the occurrence of non-pregnancy was not statistically different for categories of the risk factor describing risk of phosphorus deficiency affecting reproductive performance. However, when DMD:CP ≤8:1 and protein was unlikely to be limiting, the expected occurrence of non-pregnancy was 11.0 percentage points lower for those cows categorised as reduced risk of phosphorus deficiency adversely impacting on cow reproductive performance. This finding is consistent the current recommendation that there is limited benefit in the provision of dietary P when the available protein supply is limited (Jackson 2012).

Cows within the Northern Forest categorised as being of elevated risk phosphorus deficiency had 13.2 percentage points higher expected occurrence of non-pregnancy than compared to those categorised as being of reduced risk. Similar responses were not observed for other regions and could be explained in part due to differences in soil P status of different land systems (Jackson *et al.* 2012). The percentage of property-years within the Northern Forest with average wet season FP:ME ratio <500 mg P/kg ME was 20.6 percentage points greater than other regions with only 10.8% of property-years in this region considered to be of below average risk of phosphorus deficiency. Central Forest appeared to be the region with lowest risk for phosphorus deficiency adversely impacting cow reproductive performance as only 32.5% of property-years had average wet season FP:ME ratio <500 mg P/kg ME, which is consistent with previous publications (McCosker and Winks 1994).

The association between risk of phosphorus deficiency and foetal/calf loss was dependent on country type and BCS measured at the previous year's pregnancy diagnosis muster. The explanation for the heightened magnitude of effect for risk of phosphorus deficiency on foetal/calf loss for Central Forest compared to other regions is unknown.

For those cows categorised as being of elevated risk of phosphorus deficiency and <2.5 BCS at the previous pregnancy diagnosis muster, the expected occurrence of foetal/calf loss was 7.7 percentage points higher than those categorised as reduced risk of phosphorus deficiency. Similar responses were not observed for other BCS categories, however, generally a 2 percentage point increase in expected occurrence of foetal/calf loss was estimated for cows of elevated risk of phosphorus deficiency. The biological mechanisms for these effects are unclear however, they are potentially explained by cows in poor condition being unable to supply calves with colostrum of adequate quality to support adequate neonatal immunology or volume of milk to reduce the risk of death due to dehydration.

10.2.3.2 Assessment of environmental effects

Observed differences in animal performance between regions and pasture communities have been previously reported in the literature. However, this study is one of few studies that have quantified the effect of country type after partitioning the effects for other confounding factors. For all of the reproductive outcomes of interest in this study country type was identified as a major determinant with cow performance within the Northern Forest being substantially reduced compared to other regions after adjustment for all the other factors contained in the models. The variation in performance represented by country type that is not described by other risk factors contained in the models are likely to be associated with differences in nutrition, environment and management or alternatively further refinement of the variables considered in the final model and highlights an area for further research.

County type moderated the associated effects of BCS measured at pregnancy diagnosis (Section 10.2.3.1), time of calving (Section 10.2.3.1) and cow-age class (Section 10.2.3.3) on P4M. However, overall the percentage of lactating cows in the Northern Forest that achieved P4M was estimated to be 36%, 47% and 59% lower than that achieved by cows in the Northern Downs, Central Forest and Southern Forest, respectively. The percentage of cows non-pregnant was greatest for the Northern Forest with 32.1% failing to achieve pregnancy by September which is potentially explained by 32.2% of cows with BCS ≤2 at the weaning/branding round and cows in too poor condition to conceive after weaning.

With the exception of Northern Forest, foetal/calf loss was estimated as 4-7 percentage points higher when the THI was >79 for at least 2 weeks in the predicted month of calving. Reasons for a similar response not being observed within the Northern Forest are unclear however, the cows within this region generally contain higher percentage *Bos indicus* therefore have higher levels of tropical adaption and additionally, for some regions, such as the Barkly tablelands, there are clear differences in vegetation and the provision of shade. Under periods of thermal stress, calves are more at risk of dehydration from reduced intake by calves and the reduced milk yields of cows, likely resulting in reduced calf survival. Furthermore, periods of thermal stress could interrupt the immunological response derived from colostrum, which is dependent on quantity and timing of colostrum intake. The intestinal permeability to intact immunoglobulin is reduced to approximately 50% capacity by 6 hours after birth and none by 24 hours (Rischen 1981) and therefore increasing the risk of calves to infection if colostrum is consumed during times where it cannot be absorbed. Under chronic thermal stress reduced birth-weight and vigour following birth have also been documented (West 2003) and are also likely to be associated with reduced calf survival. Calving cows in paddocks that have adequate vegetation, providing shade or the erection of shade shelters for calves may mitigate some risk of calf loss in regions that are susceptive to prolonged periods of high THI events.

Though early-stage analyses linked season P4M and non-pregnancy it was non-pregnancynot contained in the final foetal/calf loss model and suggests that other factors explain greater proportions of variance for foetal/calf loss or the associated effects of season are adequately represented by other variables in the model. Seasonal variation observed for ecological studies is not uncommon and has led to suggestions that research studies should continue for 6-8 years to adequately capture seasonal differences (Taylor and Tulloch 1985). Seasonal variability between years is considered likely to reflect differences in nutritional and environmental conditions not accounted for elsewhere in the model. Differences between years for P4M and non-pregnancy were estimated to vary by up to 12.3 and 6.9 percentage points, respectively. However, the absence of interactions between other important explanatory factors within the P4M and non-pregnancy models and season demonstrates the consistency the other important factors are having across the range of seasons observed.

10.2.3.3 Assessment of genotype and phenotype effects

Cow-age class was identified as a major determinant for all reproductive outcomes of interest and is consistent with the literature (Entwistle 1983; Burns *et al.* 2010). The association between cow-age class and P4M was dependent on country type and average wet season FP:ME ratio (previously discussed within Section 10.2.3.1). The occurrence of cows achieving P4M was reduced for cows experiencing lactation for the first or second time, relative to mature cows. The magnitude of effect was greater for those country types considered to be associated with less nutritive value as, relative to mature cows, there was a 50 percentage points lower P4M for first-lactation cows in the Northern Forest versus 14 percentage points for first-lactation cows within the Southern Forest. These findings are consistent with the partitioning of energy towards growth, maintenance and lactation rather than reproduction in young cows (Entwistle 1983). The reduced supply of energy during reproductive processed is widely accepted to affect folliculogenesis and delay ovulation (Scaramuzzi *et al.* 2011). In contrast to other regions, the expected occurrence of P4M was similar (5-7%) for first- and second-lactation cows within the Northern Forest, which partially may be influenced by a higher *Bos indicus* content in this region as they are generally considered to be later maturing (Freetly *et al.* 2011). However, largely this effect is considered to be associated with the relatively poor nutritive value of the Northern Forest and suggests that for females to contribute three calves in three mating opportunities additional inputs are required. These findings also highlight the potential benefits of segregating pregnant and lactating young cows for preferential nutritional management.

Cow-age class was associated with foetal/calf loss with 2.5 percentage point higher foetal/calf loss for first-lactation, compared to mature cows. However, this association was dependent on mustering within a month of estimated months of calving. For first-lactation and mature cows mustered within a month of calving a 7.4 and 2.0 percentage point increase, respectively in foetal/calf loss was estimated relative to cows not mustered. It is unclear why similar responses were not observed for second-lactation and aged cows. Handling of young calves has been directly associated with calf mortality previously (Rankine and Donaldson 1968) and estimated to result in a 4 percentage point increase in calf loss (Donaldson 1962) which is generally thought to be consistent with the findings of the present study. This finding highlights the importance of timing of mustering for first-lactation cows and using foetal ageing data to inform appropriate mustering times.

Adjusted for all other predictors in the final model, the risk factor of cow hip height was a significant predictor of P4M and foetal/calf loss with overall reproductive performance decreasing with increasing categories of hip height. Tall cows (≥140 cm) were estimated to have 10.8 percentage points fewer P4M and 3.7 percentage points higher foetal/calf loss than short cows (<125 cm). Vargas *et al.* (1999) reported findings consistent with those of the present study with smaller framed cows re-establishing pregnancy earlier in the breeding season than those larger framed cows. The biological mechanism for this effect is potentially explained by the associated increased maintenance requirements of cows of larger frame size and the partitioning of nutrients away from reproduction and lactation processes. In part, hip height may also represent early lifetime reproductive performance as cows that achieved early and regular reproductive success can restrict mature size (Swanepoel 1994). Cows that achieve pregnancy whilst lactating early-in-life are considered to have increased lifetime weaning rates (Mackinnon *et al.* 1989; Johnston *et al.* 2013). Increased foetal/calf loss for cows of larger frame size is consistent with similar effects reported for first-lactation cows (Vargas *et al.* 1999). These findings highlight the importance of matching cattle grazing loads with the utilisable pasture available, which includes accounting for differences in mature size and their estimated differences in dietary pasture intake. Herd managers who select cows for reproductive success will also identify and remove cows of inappropriate size for the environmental and nutritional conditions rather than selection of cows based on small to medium frame size.

A 3.6 percentage point higher foetal/calf loss was estimated for cows that either failed to achieve pregnancy or rear their pregnancy compared to those that were observed to lactate in the previous year. Bunter *et al.* (2013) reported a similar association with reduced occurrence of calf mortality in cows, particularly 4-7 years old, that lactated in the previous year and was considered to be largely explained by teat and udder problems. The direct effect of lactation on non-pregnancy was not quantified in the present study as their effects were represented within the risk factor describing reproductive history (time of calving). However, overall, 0.9-12.5 percentage point higher (dependent on age class) expected occurrence of non-pregnancy was estimated for cows that successfully reared an October to November born calf, compared to those cows that did not did not lactate. These findings suggest that despite there being some repeatability for cows not contributing calves by either not becoming pregnant or failing to rear a confirmed pregnancy this is offset by an increased expected occurrence of pregnancy. Culling cows for not lactating during a production cycle should be preferentially directed towards those cows demonstrating evidence of inability to rear calves, eg. with teat and udder abnormalities, or where possible individually monitoring their future performance.

10.2.3.4 Assessment of infectious disease effects

As infectious disease monitoring was restricted to two of three study production years, some caution should to be exercised in the interpretation of the results as their impact has been estimated using a restricted dataset. Interactions between infectious disease factors and other factors contained in the model were not explored. Never-the-less this study is one of the few studies, if not the only study conducted within Northern Australia, which has attempted to partition the effects of other extraneous factors and quantify the impact of various infectious diseases on reproductive performance of commercial beef cattle.

This study has verified that the exposure of bovine viral diarrhoea virus (BVDV; pestivirus) at critical times has major impact on P4M and foetal/calf loss. The expected occurrence of P4M was estimated as 23.0 percentage points lower for cows within groups with high BVDV seroprevalence (>80% seropositive) compared to those within groups with a low seroprevalence (<20% seropositive). However, an assessment of the association between P4M and prevalence of recent infection was determined to be not statistically significant. This finding is potentially explained by the timing of sampling relative to the timing of breeding and the reduced sensitivity of the AGID test when used some months post-exposure (McGowan *et al.* 1993b). Group prevalence of recent infection as a predictor of foetal/calf loss was determined to be statistically significant, with 9.4 percentage points higher foetal/calf loss estimated for cows within groups of high prevalence of recent infection (>30% AGID test result ≥3) compared to those within groups with a low prevalence of recent infection (<10% AGID test result ≥3). These findings highlight the need for herd managers within northern Australia to implement practical and economical control strategies related to mitigating BVDV risk at critical times such as breeding periods. The development of such strategies may require additional targeted research activities.

Group-level results of infectious disease monitoring for bovine ephemeral fever (BEF) virus, *Leptospira hardjo* and *pomona*, and *Campylobabcter fetus* subsp. *venerealis* were not identified as statistically significant predictors of P4M in the present study. There was a trend for higher foetal/calf loss in groups that had evidence of a high level of recent infection with the pig-adapted serovar, *L. pomona,* consistent with the findings of previous studies (McGowan 2003). A 5 percentage point higher foetal/calf loss was estimated for cows within groups with high (≥30% of samples with vaginal mucus antibody) prevalence *C. fetus* subsp. *venerealis,* compared to those within groups with a low (<30% of samples with vaginal mucus antibody) prevalence. This was a somewhat surprising finding as this disease is usually associated with embryo loss that occurs before pregnancy is confirmed. These findings suggest that whilst there is evidence that infectious diseases can significantly impact on the reproductive performance of beef herds within north Australian beef herds, generally other nutritional, environmental and management factors explain greater a proportion of the variation in reproductive outcomes.

10.3 Using the findings to improve the reproductive outcome of beef breeding herds in northern Australia

This thesis has addressed various topics related to describing and identifying risk factors associated with the reproductive outcome of beef breeding herds in Northern Australia. In light of the findings of the studies presented the following conclusions and recommendations have been reached:

- There is marked variation in reproductive performance both within and between country types. The level of performance attained by the top 25% of herds was described and provides a guide for potential improvement for many businesses. However, due to biological differences within country type, not all herds will have equal opportunity for improvement and investment plans should be completed in conjunction with whole of business analyses.
- The level of reproductive performance attained by the top 25% of performing herds within the Northern Forest was much lower than that previously considered achievable and previous target weaning rates (75-80%) are generally not applicable.. A more suitable target for commercially managed mature cows is successfully rearing two calves to weaning every 3 years.
- It was identified that approximately 85% of the variation in reproductive performance for the outcomes of interest in the studies relevant to this thesis rested at the annual production cycle-level. Therefore, interventions by herd managers to improve reproductive performance are likely to be most effective if directed at the annual production cycle-level rather than the herd-level. Thus, the use of individual animal recording systems to monitor and manage individual animal performance should be recommended to facilitate the ongoing future improvement of beef herds within northern Australia.
- This study successfully described the management practices and some nutritional and environmental parameters for the source population. There were large variations in the size of breeding herds and properties, and their degree of development, within and between country types. The nutritional information summarised in this study highlights that pasture

quality during the dry season is unlikely to maintain cow condition for much of northern Australia. Additionally, as indicated by FP:ME, it appears that available wet season P is likely to limit animal production for much of Northern Forest.

- The findings of the studies presented reaffirm that lactation, time of calving and indicators of body reserves (BCS) measured at critical time points are highly important determinants for all reproductive outcomes. Thus, management strategies that support the management of lactation and its correspondence with pasture of adequate quality and quantity are critical, particularly in the Northern Forest. In addition, these major determinants should form the basis of any individual or group-based herd performance monitoring systems.
- These studies further validated the known impact nutrition has on the efficiency cows achieve pregnancy and its association with foetal/calf loss. Major nutritional impacts were considered to be caused by phosphorus adequacy, protein content, available pasture, and seasonal conditions. Grazing and rangeland management, maintained by strategic supplementation are key to providing a nutritional profile capable of supporting efficient reproductive performance within north Australian beef herds.
- Mustering within a month of calving months and the risk factor describing mustering efficiency, which is likely to relate the herd-mangers ability to impose group-level interventions/activities were ranked as highly important risk factors with respect to foetal/calf loss and are under the potential direct control of herd managers.
- While there was evidence that infectious diseases under some situations caused significant impact on reproductive performance the consistent impact of nutritional and environmental factors on foetal/calf loss were highlighted in this study and challenges previous theories that infectious disease and animal factors were likely to be the major determinants of foetal/calf loss. There was no significant association between group prevalence for antibody against neosporosis, leptospirosis, bovine ephemeral fever or *Coxiella burnetti*
- The infectious diseases BVDV (pestivirus) and vibriosis had significant impacts on reproductive performance. Despite widespread evidence of botulism in Northern Downs and Forest, a concerning proportion of the study population did not vaccinate cows. In light of these findings best-practice control measures should be maintained for all three diseases.

10.4 Potential future research

The study has also identified a number of research needs and these are summarised below:

- The studies presented in this thesis were primarily focused on describing reproductive performance and the identification of important associations between risk factors and reproductive performance. Therefore, it is not known if the determined achievable levels of monitored performance reflect the maximum economic value. Further business analysis to compare the management that attained upper and lower 25% levels of performance would quantify the association between reproductive performance and profitability within country types, and potentially identify economically sound management strategies that lessen the impact of significant risk factors.

- The overall residual variation attributable to the property-level effects not explained by the fitted predictors for all explanatory models was relatively large. Therefore, further improvement to the modelling of these reproductive outcomes could result from the identification and inclusion of further risk factors explaining a greater proportion of the between property variance, or further refinement of the variables considered.

- The reproductive performance of beef breeding herds within the Northern Forest varied vastly from that of other regions with the association of some factors and reproductive performance operating differently within this country type such as BCS measured at pregnancy diagnosis and the indicator of heat stress. As such, other extraneous factors not identified in the present study may be operating within this region and moderating the association of major determinants of reproductive performance. The potential identification of these factors would allow more targeted remedial actions within this region.

- Changes in BCS during the wet season and its value prior to calving are major determinants of reproductive performance. Identifying and ranking the major determinants of cows achieving adequate BCS prior to calving and minimising its loss during lactation, whilst partitioning the effects of other determinants is warranted to quantity the direct and moderating effects of risk factors. This information would better inform the development of low cost remedial management strategies and improve reproductive performance, and potentially profitability, of beef breeding businesses within most regions, particularly Northern Forest.

- This study identified major associations between risk factors and foetal/calf loss though their biological mechanism is unclear. However, it is speculated that these factors are associated with either inadequate neonatal immunology due to reduced intake of colostrum of adequate quality within critical time points or inadequate volume of milk to reduce the risk of death due to dehydration. Further research to understand the causal factors associated with foetal/calf loss may inform appropriate managerial interventions to mitigate their impact.

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